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THE EFFECT OF HAZE ON SPECTROSCOPIC MEASURES OF THE SOLAR ROTATION: EXPLANATION OF DIFFERENCES IN VALUES, AND DIFFERENCES DEPENDING ON THE INTENSITIES OF SPECTRUM LINES.

BY RALPH E. DE LURY.

SPECTROSCOPIC determinations of the rate of the sun's rotation by different observers at various times, present remarkable and puzzling differences. Certain sources of error have been proven to be present; but other explanations of some of the differences are of a hypothetical nature and are veiled in doubt. It is the object of this note to present with supporting evidence, a new interpretation which seems to clear up much of the uncertainty attached to the problem of the rolar rotation.

DIFFERENCES IN SOLAR ROTATION MEASURES.

Notable observed differences are:—

(1). *The measurements of the solar rotation made by different observers exhibit a large range of values.* For example, the values of the equatorial solar velocity, derived from about twenty

For references see page 357.

groups of determinations, range from 2.11 to 1.86 km./sec. Furthermore, *measurements by the same observer of a series of observations taken over a short interval of time frequently show a considerable range in their values.*

(2). *Some observers have found a difference in velocity for different spectrum lines, while others have not.* The determinations by Adams and Miss Lasby at Mount Wilson in 1906-8 show such differences[1], and this is confirmed[2] in 1915 by St. John, Adams and Miss Ware, and also in Ottawa by the writer in 1915, —a summary of these measurements being given later in this paper. On the other hand, all other observers (the writer included) find no serious differences for different lines in the interval, 1909-13. Hence the conclusion: *The difference in velocity for different spectrum lines is a variable, being present in some observations and apparently absent from others.*

(3). *One observer found that the north and south hemispheres of the sun rotated at different rates.* The observations of Hubrecht at Cambridge[3] alone give information on this point. In 1911 the writer suggested the method of using simultaneous exposures from the centre of the solar disc and from the limbs for determining the rates of rotation in the two hemispheres independently[4], and since the apparatus was received in 1913 he has been making such observations; and in 1915 a similar method was started at Mount Wilson[2], so that more evidence on this point will soon be at hand.

(4). *Some observations show a value of the rate of rotation progressively increasing with wave-length over the small range of wave-lengths covered by a plate; a great many more observations do not exhibit this effect.* The 1906-7 series[1] of Mount Wilson measurements show this effect; while the 1908 series[1] does not. Some measurements by Schlesinger in 1909, and those by Hubrecht[3] in 1911 show the effect. All other observations appear to be free from this effect.

The following explanations of the above results have been or may be offered:

MECHANICAL EXPLANATIONS OF DIFFERENCES.

(*a*). *Instrumental Errors.* Such instrumental errors as would be caused by uneven illumination of the prism or grating, combined with observations of the spectrum out of focus, may account for part of the results (1), (3) and (4).

(*b*). *Observational Errors.* Small inaccuracies in determining the points observed are possible, but it is unlikely that these could ever equal 0.5 per cent.

(*c*). *Errors of Measurement.* In 1910 the writer suggested that errors of measurement might account for (1) and (2). He tested this explanation of (2) by mechanically introducing displacements of the spectrum lines the same for all lines and of configurations and magnitudes of displacement similar to actual observations; a slight tendency to systematic difference for different lines was found in a series of 12 of these "artificial" rotation plates, as well as a systematic difference depending on the direction of the plate[5]. These plates were taken in the λ4250 region, where Adams and Miss Lasby found the differences for different lines[1], and the plates were sent to them in the hope that their measures of the same lines mchanically shifted would settle the question as to whether the differences for different lines in their original measurements were due to personal errors. Unfortunately, they did not have time for the measurements, so the part played by systematic error of measurement in their 1906-8 determinations remained unsettled. This explanation of (1) was tested by having various observers measure the same lines on the same plates. J. S. Plaskett kindly offered to co-operate with the writer in measuring the above twelve plates of the mechanical shifts, with the result that a systematic difference between the two measures of about 2 per cent. was discovered. This difference persisted throughout the measurements of the solar rotation in 1910-13. These suggestions of the writer, followed by the comparative measurements, led to these recommendations made at the Meeting of the International Solar Union, held at Bonn in 1913: "It is highly desirable to trace

to their source the systematic differences that are found in the values of the solar rotation by different observers, . . . Investigation should also be made into the personal differences that are found in measures of the same plates by different observers." (In this connection it would seem advisable to have a series of plates, say one or two from each observer, measured by the automicrophotometer at Mount Wilson, and then passed around among the various observers for measurement.)

PHYSICAL EXPLANATIONS OF DIFFERENCES.

The above explanations are based upon the possibility of instrumental, observational or personal errors; those which follow are based on physical considerations:

(*d*). *Convection in the solar atmosphere.* Local convection currents undoubtedly account for some of the differences obtained by the same observer under apparently similar conditions (1), and it is quite possible that in small series of observations the mean may be considerably distorted by this cause. Adams found instances of such local motions in the neighborhood of spots[1]. The writer found in one case a difference of 8 per cent. between the top and bottom of a spectrum 1 mm. wide, the lines being quite visibly bent from their normal straightness.

(*e*). *Periodic variation in the rate of the solar rotation.* From variations in the visual measurements of Duner (at Upsala, 1887-9 and 1899-1901), and Halm (Edinburgh, 1901-6), the latter suggested that there was a periodic change in the sun's rate of rotation. If such is the case (1) could be accounted for, partially, at least; and since there is periodicity in sun spots and a symmetry in the spottedness of the north and south hemispheres, number (3) might result from such periodic variation; and possibly result (2) could be explained by such periodicity, for the evidence on this point seems to run with the Sun spot variation.

(*f*). *Variation in the angular rate of rotation, depending on level in the solar atmosphere.* When Adams discovered differences in angular velocity for different spectrum lines (2), he suggested[1] that it was due to the fact that the gases producing the

different lines existed at different levels (an assumption apparently supported by other lines of evidence) and that the angular rate of rotation increased with elevation. To account for the additional facts mentioned in (2) above, this explanation would have to be modified by adding: *and such variation in the angular rate of rotation varies periodically.*

(*g*). *Sky Spectrum.* Halm noted the possibility of error caused by the sky spectrum blending with the displaced limb spectrum, and observers have for the most part been careful to select the clearest days for observation. However, there seems to be error due to this source in some of the observations. The writer made, in 1911, some tests of the effect of sky spectrum in lessening the rotation displacement, with the result that for the very clearest days there seemed to be little error from this source[6]. This work led into the consideration of the general question of blended spectra, and in 1912 measurements of blends of limb and centre spectra were made which showed a striking, though predicted, relationship between measured displacements and line-intensity, due to the fact that the difference in intensity for a line at limb and at centre increases in general with decrease in intensity of the line[7]. These results led to the following explanation (*h*), mentioned previously though presented only now, because recent results in the measurement of the solar rotation at Ottawa by the writer, and at Mount Wilson[2] by St. John, Adams and Miss Ware are strikingly well explained by it:

(*h*). *Haze Spectrum.* It has been shown[7] (see also later) that a variable haze, between the observer and the Sun, causing to be blended on the limb spectrum a spectrum of variable intensity and of character somewhat similar to that of the centre of the solar disc in regard to intensity and wave-length of the spectrum lines, causes: (*i*) the spectroscopic determinations of the solar rotation to vary, and (*ii*) the velocities of rotation from the different lines to decrease in general with decrease in intensity of the lines, the amount of the velocity decrease for a given line depending on the strength of the haze continuous spectrum relatively

to the limb continuous spectrum, and on the ratio of the intensities of the line in the haze spectrum and in the limb spectrum. Observations already made, make it seem probable that the variable terrestrial atmosphere and its clouds and hazes is sufficient to account for differences (1) and (2) above, after eliminating the systematic and accidental errors mentioned above. But if in any series of observations the terrestrial haze spectrum can be proven of insufficient strength, then we may call in the idea of haze existing between the earth and the sun, near the sun, or even in the solar atmosphere (such as produced by matter falling in variable amounts into the sun and requiring an interval of time before being swept along in the general rotation). Such a variable haze could possibly account for the differences in the solar radiation observed by Abbot and others; it would be interesting to make simultaneous observations of solar rotation and radiation to see if the changes in their values synchronize.

That explanation (*h*) is the true explanation of the residual differences in numbers (1) and (2) above, after due allowance has been made for the other known sources of error, seems established from the similarity of the following three series of results, dealing with measurements of blended spectra, measurements of the solar rotation at Ottawa on plates made during different strengths of haze, and measurements of the solar rotation made at Mount Wilson:

MEASUREMENTS OF BLENDED SPECTRA.

In the paper cited[7], it has been shown that the measured rotational displacements of the lines from the limb when blended with the lines—undisplaced by rotation—from the centre of the solar disc decrease progressively with decrease in the intensity of the lines; and this was explained as due to the fact that the difference in intensity between lines in the centre and limb spectra decreases, in general, with increase in intensity of the lines. There are exceptions to this latter generalization which serve to test the various theories (see later). The following summary of the first

Table in the paper quoted[7] will suffice to illustrate the general results:

TABLE I, BLENDED SPECTRA, λ5600.

Mean displacements of equatorial limb lines blended with five different blends, in which the ratios of the densities of the deposits on the photographic plate of limb continuous spectrum to total continuous spectrum were, 0.89, 0.83, 0.74, 0.62 and 0.54; mean ratio, 0.72.

Plate, *L*854, Sept. 20, 1911.

Line—Intensity, centre	1	2	3	4	5	6	8
Line—Intensity, limb .	0	1—	2	3	5—	6—	7
Line—Width, centre ...	4.8	4.2	5.4	6.8	7.8	7.2	9.2 km./sec
Line—Width, limb	6.2	5.6	5.8	6.6	8.2	8.0	8.6 km./sec.
No. of lines	3	6	5	2	1	1	1
Mean Velocity from blends	1.553	1.573	1.575	1.594	1.633	1.648	1.651 km./sec.
Equatorial Velocity not blended	2.026	2.053	2.014	2.053	2.085	2.085	1.978
					Mean, 2.042		km./sec.

It is thus seen that the lessening of the rotation displacement in the blend with the centre spectrum is greater progressively with decrease in intensity of the line, which in turn, is accompanied by steadily increasing values of the ratio, centre intensity to limb intensity, and decreasing values of the ratio, centre width to limb width. (Thus decreasing intensity at the limb seems to be accompanied by increasing width. To explain this the writer has advanced the hypothesis that the widening and weakening of the lines at the limb is due to convections similar to those in the penumbral regions of spots. Other factors come into play and account for many exceptions. The question will be discussed soon in another communication.)

MEASUREMENTS OF THE SOLAR ROTATION AT OTTAWA ON HAZY DAYS.

The results from the measurements of the solar rotation on hazy days, for varying degrees of haze show a striking similarity to those from the measures of the artificial blends as follows:

TABLE II, SOLAR ROTATION, λ5200.

March 11, 1:30 p.m., 1916, very slightly hazy, 6 *double* observations, *i.e.*, 2 strips of spectrum from each limb.

					Mean
Intensity	1	2	5.3	22	5.3
No. of lines	3	11	7	3	24
Equatorial Velocity	1.956	1.972	1.972	1.963	1.967 km./sec.

TABLE III, SOLAR ROTATION, λ5200.

June 16, 4.15 p.m., 1915, slightly hazy, 6 double observations.

					Mean
Intensity	1	2	5.3	22	5.3
No. of lines	3	11	7	3	24
Equatorial Velocity	1.808	1.842	1.845	1.883	1.843 km./sec.

TABLE IV, SOLAR ROTATION, λ5200.

March 3, 12.55 p.m., 1916, very hazy, haze varying, 3 double observations.

					Mean
Intensity	1	2	5.3	22	5.3
No. of lines	3	11	7	3	24
Equatorial Velocity	1.738	1.760	1.814	1.887	1.816 km./sec.

It will be thus seen that the percentage difference between the values for intensity 1 and 22 are: Table II, 1.2; Table III, 4.6; Table IV, 8.2. After the observations of Table IV were made, a photographic comparison of the intensity of haze spectrum relatively to limb spectrum was secured; however, the haze was continually varying, so that only a rough approximation could be arrived at, and from this it would seem that the average ratio of intensity of haze continuous spectrum to limb haze continuous spectrum for the observations of Table IV was 12 per cent. This would involve the assumption that the haze in Table II. was about 2 per cent., while the haze for observations of Table III was about 7 per cent. These are of course only rought estimations, but they serve to point out the necessity of very accurate measures of the relative strengths of haze spectrum and limb spectrum. When such are made and accurately correlated with solar rotation measurements for groups of lines of different intensities, it will be possible to eliminate the effect of haze spectrum from any similar series of rotation measurements. Such being the case, it should be

possible to estimate the strength of haze present during the Mount Wilson observations[2].

MEASUREMENTS OF THE SOLAR ROTATION AT MOUNT WILSON.

TABLE V, SOLAR ROTATION, λ5200.

1914-1915 measurements[2].

					Mean
Intensity	1	2	4.9	22	5.4
No. of lines	2	5	9	3	19
Equatorial Velocity	1.924	1.933	1.945	2.043	1.950

It is thus seen that the difference between the values for lines of intensity 1 and 22 is 6.1 per cent. It would seem that, if this is altogether ascribable to haze, there was an overlapping haze spectrum of about 9— per cent. in there observations. The 3 lines of average intensity 22 were the same as in the Ottawa observations, namely, the three strong Mg lines in the *b* group, λ5167 to λ5184, but the lines of intensity 1 could easily yield different results in the two series, 3 in the Ottawa observations and 2 in the Mount Wilson observations. However, it seems likely that there must have been a considerable haze effect during the latter observations. The large difference between the values of the rotation in the two series is probably accounted for by some of the other sources of error, though the Ottawa values in Table II (very slight haze), are nearly the same in the mean, the strongest lines being, however, exceptionally high in the Mount Wilson measures. That is a question which can best be attacked after the influence of haze spectrum has been accurately eliminated.

MEASUREMENTS TO TEST THE LEVEL HYPOTHESIS.

The following measurements of the solar rotation seem to

TABLE VI, SOLAR ROTATION, λ4500.

Ottawa, June 30-July 25, 1910, 32 observations.

				Mean
Intensity	0.7	8.5	4.6	
No. of lines	6	6	12	
Penumbral displacements	+0.028 Å.U.	—0.001 Å.U.	+0.015	
Equatorial velocity	1.968 ± 0.003	1.972 ± 0.007	1.970 ± 0.004 lines ± 0.010 plates	
Seven of the above plates taken on cloudy or hazy days, yield:				
Equatorial velocity	1.909	1.939	1.924 km./sec.	

support the haze explanation and to disprove the level hypothesis, unless the latter be assumed to be variable, as pointed out above:

TABLE VII, SOLAR ROTATION, λ5600.

Ottawa, December 6-12, 1910, 32 observations.

				Mean
Intensity	1.6	6.2	3.9	
No. of lines	5	5	10	
Equatorial velocity	1.930 ± 0.006	1.936 ± 0.002	1.933 ± 0.003	lines
			± 0.005	plates

In Table VI are given the measurements of 6 lines of intensities 0 and 1 paired off with 6 lines of intensities 4 to 15, giving a great difference in penumbral displacements in spots, interpreted as indicating range in level in the reversing layer (Evershed and St. John)[8]. If Adams' hypothesis of increasing angular velocity for increasing elevation in the sun be true, there should be a considerable difference between the velocities of rotation from these two groups of lines. There is no appreciable difference, however, and the results of Table VII show this also. We are thus forced to abandon the level hypothesis, or else modify it by adding the idea of variability. From the seven plates of Table VI taken on days when the haze spectrum was stronger than for the other plates, it is seen that there is a difference between the velocity determinations of the two groups of lines, of 0.030 km./sec.,—a difference explainable by the haze spectrum blending with the limb spectrum. The mean value of the December determinations, Table VII, is smaller by 2 per cent. than the value from the July determinations, Table V, possibly due to the lower declination of the sun in December and to the lower mean intensity of the lines, as well as to the probably greater relative strength of the sky spectrum in December than in July.

SOME GENERAL DISCUSSIONS.

It has been mentioned that observers during 1909-13 found little difference for different lines. Can this be due to the fact that at sun spot minimum there is less danger from the error due to haze than during sun spot maximum, pointing either to the presence of varying quantities of matter about the sun or to vary-

ing haziness in the terrestrial atmosphere caused by the variation in its ionization depending on the spot activities? In most of these 1909-13 observations the lines were not considered in groups as to difference in intensity, but rather with regard to the element producing the line, in accordance with the recommendations of the Solar Union in 1910,—the important relationship between penumbral displacements and intensity and level[8] not having been fully developed at that time. It would seem advisable to investigate the published results from this point of view. This has been done in a preliminary way by the writer. Some results show no appreciable relationship of velocity with line intensity, some show evidence of this, and some seem to indicate the reverse of what would be expected from Adams' level hypothesis, *i.e.*, a lower rate of rotation with increasing level, a physically possible and quite probable state of affairs. Some exceptions to the level hypothesis are readily explained on assumption of blended haze spectrum, *e.g.*, line λ4287.566 of intensity 1 at the centre of the solar disc is strengthened and widened at the limb, and it has a penumbral displacement of 0.026 Å.U., which interpreted as meaning low level, it is to be expected on the level hypothesis that this line should give a lower rotational value than the mean. Adams and Lasby find[1] in 1908 that this line has an equatorial velocity 0.004 km./sec. above the mean; this is explainable by the fact that this line is strengthened, not weakened, at the limb, and therefore should yield a larger value than the mean of the other lines which are for the most part weakened at the limb, if there be haze spectrum of sufficient strength. In those measurements the lines that are weakened at the limb show a mean residual of —0.003, while the lines that are strengthened at the limb show a residual of +0.005 in the mean, indicating a slight sky spectrum effect. Similar means, —0.002 and +0.005, occur in the 1906-7 series. All published results should be discussed fully from this point of view so that a correction can be made in the absolute values. A knowledge of the behavior of the lines at the limb is essential. Is it possible that the results (4) can be due to chance selection of the lines so

that at one end of the plate the lines will yield a smaller value of the rotation than do the lines at the other end? A cursory examination of Hubrecht's results would make this seem a possible explanation. It is assuredly not a physical effect depending on wave-length, for if it were so there should be profound differences between series taken at widely different parts of the spectrum, and this is not the case. It may possibly be due to uneven illumination of the grating and one end of the plate being slightly out of focus. (It is possible too that Hubrecht's result (3) may also be due to blended haze spectrum inasmuch as the wave-lengths in the latter are not midway between those from opposite limbs, which would result in effects of blending of different magnitude for the two limbs.) It seems to the writer that many of these puzzling differences will vanish when accurate determinations of the haze spectrum effects are made. A later communication will deal with the effect in various series of observations.

SUGGESTIONS FOR FUTURE OBSERVATIONS.

In the meantime it is necessary for all observers to pay special attention to the influence of haze spectrum; it can be eliminated by exactly correlating changing values of the solar rotation differences in value for different intensities of lines, say from two groups of lines, one greatly weakened at the limb and the other not weakened at the limb. The λ5200 region offers the best chance for such measurement as the strongest lines there are quite measureable, and it is possible to eliminate instrumental and other errors by using either iodine or chlorine comparison spectra (as suggested[9] by the writer in 1910 and 1911, and employed by him since the installation of the limb and centre prism apparatus in 1913). For these reasons I would suggest that it be considered as a common region, even in preference to the λ4250 region formerly chosen.

CONCLUSIONS.

The main conclusions from the above investigation are:

I. Haze spectrum, likely altogether terrestrial in its origin, accounts for much of the variation in the values of the solar rota-

tion obtained by various observers at different times. Variations hitherto ascribed to the sun appear to be due to variations in haze.

II. Haze spectrum, being different in character to limb spectrum, the difference depending in general on the intensity of the line, blends with limb spectrum in such a way as to make it appear that different spectrum lines yield different values for the velocity of rotation of the sun. Such differences found in measures of the solar rotation at Mount Wilson and at Ottawa, are satisfactorily explained in this manner.

The writer wishes here to pay a tribute to the memory of the late Director of this Observatory, Dr. W. F. King, whose warm interest in the solar Physics work and whose encouragement, especially in the testing of new ideas, was greatly appreciated by the writer.

SOLAR PHYSICS DIVISION,
DOMINION OBSERVATORY,
OTTAWA, CANADA
April, 1916.

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[6] De Lury, Report of the Chief Astronomer, Ottawa, 1911, p. 281.

[7] De Lury, JOURNAL ROYAL ASTRONOMICAL SOCIETY OF CANADA, 10, 201, 1916.

[8] Evershed, Kodaikanal Observatory *Bulletin*, 15, 1909.

St. John, *Contributions* Mount Wilson Solar Observatory, Nos. 69, 74. *Astrophysical Journal*, 37, 322, 1913; 38, 341, 1913.

[9] De Lury, Report of the Chief Astronomer, Ottawa, 1910, p. 168; 1911, p. 293.

ORBIT OF THE SPECTROSCOPIC BINARY χ AURIGÆ.

By Reynold K. Young.

THE binary character of χ Aurigae ($\alpha = 5^h\ 26^m$, $\delta = +32°\ 7'$ Mag. 4.88, Type *B* 1) was announced by Frost and Adams in the *Astrophysical Journal* in 1903. An orbit has been determined from eighty-eight single-prism spectrograms secured at this observatory during the years 1913, 1914, 1915 and 1916. An idea of the spectrum may be obtained from Table I, which gives the wave-lengths of the lines used in making the reductions, the number of times each line was measured and other data necessary for correcting the wave-lengths by the usual method of making the weighted mean of the residuals equal to zero. The residuals quoted are taken in the sense, observed minus the mean of the plate. In addition to the lines given in this table the *H* and *K* lines of calcium are present and generally were measured, but they were not included with the rest of the lines for reasons which will appear later. On well exposed plates all of the lines given are fairly sharp. Those due to silicon and some of those due to helium are faint, which accounts for the small number of times they were measured.

The velocities obtained at the Yerkes and Ottawa observatories follow in Tables II and III. The headings of the columns in these tables are self-explanatory. The residuals given under O – C were obtained graphically from the final curve, and so may occasionally be a tenth of a kilometer or so in error.

TABLE I.

Element	Wave-Length	Arithmetic Residual	Algebraic Residual	Total Weight	Number of times Measured
Helium	3964·875	7·5	+ 2·1	10½	32
Helium	4009·417	6·8	+ 2·1	8	23
Helium	4026·352	5·7	+ 2·9	39½	79
Hydrogen	4101·890	5·8	− 0·6	30½	64
Helium	4121·016	8·3	− 0·9	5½	19
Silicon	4128·211	10·0	− 3·2	9	29
Silicon	4131·047	6·2	− 2·7	7¼	24
Helium	4143·928	7·7	− 3·1	22½	61
Carbon	4267·301	7·1	+ 2·8	13½	40
Hydrogen	4340·634	6·7	− 3·0	48¼	83
Helium	4388·100	7·2	− 1·3	37	76
Helium	4471·676	6·1	+ 3·2	63	86
Magnesium	4481·400	5·7	− 1·2	34	72

TABLE II.

YERKES OBSERVATIONS OF χ AURIGÆ

Date	Julian Day	Velocity	O−C
1903			
Sept. 5	2,416,363 825	+ 24·2	+ 12·8
Oct. 10	398·782	+ 12·2	− 2·4
Oct. 16	404·844	+ 13·8	− 1·2

TABLE III.

OTTAWA OBSERVATIONS OF χ AURIGÆ

Plate	Obs.*	Date	Julian Day	Velocity	Wt.	O – C	Vel. H and K lines	Wt.
		1913						
5791	P′	Nov. 4	2,420,076·915	– 19·8	1	+ 0·5	– 10·6	1
5798	Y	" 5	077·872	– 17·5	1	+ 2·7	– 11·8	½
5804	Y	" 6	078·719	– 20·6	1	– 0·5		
5818	P′	Dec. 8	110·774	– 19·2	½	– 3·4	– 12·7	1
5834	Y	" 18	120·628	– 9·8	½	+ 4·5	– 9·5	1
5849	C	" 22	124·780	– 22·3	½	– 8·7	– 1·9	½
		1914						
5873	Y	Jan. 1	134·729	– 14·6	½	– 2·7		
5894	P	" 21	154·705	– 14·5	½	– 5·9	+ 2·7	½
5922	P′	Feb. 9	173·689	– 15·2	½	– 9·7		
5925	Y	" 11	175·663	+ 1·5	1	+ 6·9		
5939	Y	" 15	179 589	– 2·5	1	+ 2·0		
5957	C-P′	" 23	187·665	+ 6·7	1	+ 9·9	+ 1·8	½
5973	Y	Mar. 11	203·576	– 8·4	1	– 7·7	+ 1·3	½
6397	Y	Sept. 17	393·889	+ 7·6	1	– 10·2	– 6·0	1
6460	Y	Oct. 1	407·839	+ 17·6	1	– 0·3	+ 8·9	1
6470	C	" 2	408·833	+ 29·1	½	+ 11·3	+ 15·2	½
6483	H	" 4	410·822	+ 18·0	1	+ 0·1	+ 12·5	1
6486	Y	" 6	412·914	+ 22·2	1	+ 4·3	+ 16·9	1
6489	Y	" 11	417·887	+ 21·1	1	+ 3·3	+ 11·0	1
6508	H	" 20	426·791	+ 19·0	1	+ 1·3		
6526	Y	" 22	428 911	+ 24·7	1	+ 7·1	+ 13·6	1
6562	H	Nov. 17	454·824	+ 17·8	1	+ 1·2	+ 9·9	1
6587	P-Y	" 28	465·748	+ 5·2	1	– 12·5	+ 3·2	½
6593	C-P′	Dec. 4	471·757	+ 20·8	1	+ 5·8	+ 12·3	1
6599	Y	" 5	472·759	+ 16·4	1	+ 1·4	+ 17·5	1
6604	Y-H	" 6	473·627	+ 13·3	1	– 1·6	+ 7·1	½
6617	C-P′	" 11	478·733	+ 10·7	1	– 3·7	+ 10·5	1
6627	Y	" 15	482·637	+ 14·6	1	+ 0·6	– 3·7	1
6639	P′	" 16	483·757	+ 15·8	1	+ 2·0	– 0·1	1
6643	H	" 17	484·654	+ 14·5	1	+ 0·8	+ 11·2	1
6646	Y	" 20	487·496	+ 15·3	1	+ 1·9	+ 3·4	½
6652	Y	" 22	489·592	+ 10·4	1	– 2·8	+ 6·2	1
6667	Y	" 30	497·571	+ 16·2	1	+ 3·9	+ 8·9	1
		1915						
6680	C	Jan. 4	502·744	+ 11·7	1	+ 0·2	+ 6·9	1
6702	Y	" 10	508·592	+ 1·4	1	– 9·1	+ 7·2	1
6731	Y	" 24	522·609	+ 7·5	1	– 0·5	+ 3·6	½
6750	H-Y	" 28	526·721	+ 8·1	1	+ 1·0	+ 6·7	1
6783	C	Feb. 12	541·640	+ 6·2	1	+ 2·1	+ 9·3	1
6788	H	" 17	546·599	+ 11·2	1	+ 8·3	+ 8·8	1
6819	Y	" 28	557·604	– 2·8	1	– 3·2	– 1·1	1
6844	Y	Mar. 7	564·573	+ 1·7	1	+ 3·2	– 2·6	1
6879	Y	" 19	576·555	– 11·3	1	– 6·8	+ 4·8	1
6896	Y	" 30	587·528	– 4·8	1	+ 2·3	0·0	1
6919	Y	Apr. 13	601·536	– 6·8	1	+ 4·1	– 5·6	1
6956	Y	" 28	616·556	– 17·3	1	– 2·7	– 18·0	½
7135	Y	July 29	707·858	– 21·8	½	+ 0·7		1

TABLE III.

OTTAWA OBSERVATIONS OF χ AURIGÆ—(*Continued.*)

Plate	Obs.*	Date	Julian Date	Velocity	Wt.	O − C	Vel. H and K lines	Wt.
		1915						
7152	H'	Aug. 10	2,420,720·851	− 24·5	1	− 3·2		1
7175	Y	" 26	736·826	− 18·7	1	+ 0·9		1
7199	Y	Sept. 2	743·883	− 21·6	1	− 2·8		
7227	Y	" 9	750·906	− 16·8	1	+ 1·1		
7264	P''	" 17	758·875	− 11·8	1	+ 5·0		
7280	H	" 21	762·900	− 13·9	1	+ 2·2	− 3·7	½
7316	Y	" 30	771·881	− 22·2	1	− 7·4	− 11·7	½
7323	Y	Oct. 9	780·816	− 7·1	1	+ 6·3	− 12·9	½
7345	C	" 15	786·816	− 2·2	1	+ 10·3		
7364	Y	" 24	795·892	− 12·2	1	− 1·2	− 0·6	½
7373	Y	Nov. 3	805·622	− 9·8	1	− 0·3	− 6·6	1
7384	Y	" 6	808·862	− 14·6	1	− 5·7		
7401	H	" 12	814·740	− 5·3	1	+ 2·6	+ 10·1	1
7415	C	" 17	819·625	− 16·6	½	− 9·5		
7429	Y-C	" 24	826·703	− 1·4	1	+ 4·4	− 2·4	½
7440	Y	Dec. 3	835·570	+ 6·4	½	+ 10·7		
7447	C	" 10	842·622	− 4·9	1	− 1·7	+ 1·5	1
7454	P	" 20	852·649	− 9·2	1	− 7·7	− 3·9	½
7458	Y	" 28	860·651	+ 3·0	1	+ 3·2	− 8·0	½
		1916						
7475	C	Jan. 7	870·514	− 5·8	1	− 7·0	+ 4·5	1
7481	H	" 13	876·569	− 2·0	1	− 4·0	+ 1·8	½
7494	Y	" 28	891·574	+ 2·6	1	− 1·6	+ 0·3	1
7502	H	Feb. 3	897·728	+ 12·6	1	+ 7·6	+ 12·6	1
7504	Y	" 10	904·584	+ 6·2	1	+ 0·2	+ 11·6	1
7510	P	" 19	913·669	+ 13·5	1	+ 6·3		
7512	Y	" 20	914·501	+ 9·4	1	+ 3·1	+ 5·3	1
7517	C	" 23	917·629	+ 6·5	1	− 1·1	+ 8·5	1
7527	Y	" 29	923·524	+ 1·8	1	− 6·6	+ 5·4	1
7532	C	Mar. 1	924·501	+ 4·8	1	− 3·7	− 2·0	½
7536	H	" 2	925·624	+ 8·5	1	− 0·1	+ 3·9	1
7539	Y	" 5	928·534	+ 0·9	1	− 8·1	+ 6·1	1
7542	C	" 10	933·535	+ 10·8	1	− 1·3	+ 10·1	½
7549	Y	" 17	940·597	+ 11·5	1	+ 1·2	+ 4·2	1
7550	Y	" 17	940·642	+ 8·8	1	− 1·5	+ 5·5	1
7558	Y-H	" 19	942·637	+ 8·5	1	− 2·1	+ 9·2	½
7562	Y	" 21	944·510	+ 14·0	1	+ 3·2	+ 11·7	1
7571	H	" 23	946·618	+ 14·8	1	+ 3·8	+ 6·5	1
7585	Y	" 30	953·575	+ 7·8	1	− 4·0	+ 7·8	1
7594	Y	Apr. 2	956·572	+ 9·0	1	− 3·0	+ 3·7	1
7601	H	" 5	959·525	+ 16·5	1	+ 4·2	+ 13·0	1
7624	Y	May 2	986·548	+ 9·2	1	− 5·5	+ 0·3	½
7632	H	" 4	988·555	+ 26·1	½	+ 11·2	+ 17·4	½

*C = Cannon. H = Harper. P' = Parker. P = J. S. Plaskett. P'' = H. H. Plaskett. Y = Young.

The period is remarkably long for an early type star, and it so happens that the observations taken at the Yerkes Observatory fall almost at the top of the curve, so near this point, in fact, that in the preliminary elements it was impossible to decide on which branch of the curve they should lie. For this reason, and also because there is generally a systematic difference between radial velocities obtained at the two observatories, the period was determined from the Ottawa observations alone. As it turned out, the inclusion of the Yerkes Observatory plates would have yielded practically the same result, for the final orbit gives a mean residual for their plates of +3.1 km., which is just about the difference usually found between measures made by the two observatories. Seventeen normal places were formed as given. It is unfortunate that the negative minimum is not more strongly determined, but the lack of observations is due to the star and sun being in conjunction at that time. If the star were followed for another revolution this defect could be remedied. In order to determine the period accurately, the star should be observed at some epoch in the future which can be so chosen as to define the negative minimum.

The final elements given are the result of a least squares solution.

FINAL ELEMENTS

P =	655·16	± 5·26 days
T =	J.D. 2,420,629·78	± 9·56 days.
ω =	135°·52	± 5°·2
e =	0·171	± 0·026
K =	20·53 km.	± 0·57 km.
γ =	− 0·15 km.	± 0·35 km.
$a \sin i$ =	182,300,000. km.	
$\frac{m_1^3 \sin^3 i}{(m+m_1)^2}$ =	0·56 × sun.	

THIRD BODY.

It will be noticed that the binary character was announced from three plates, which the orbit shows to fall near the epoch of

positive maximum (cf. radial velocity curve, Fig. 2). In the interval covered by these plates the variation should be small and the velocities increasing. One is forced to conclude that there is another period superimposed upon the one found, or that the announced variation means nothing. The spectrograms have been remeasured at the Yerkes Observatory, and Professor Frost finds no reason to doubt that the range indicated by the velocities is real.

We have been unable to find a period for this variation. Several periods would harmonize some of the larger residuals and so reduce the sum Σpv^2 a little, but the fact that there are several which look equally good (or bad) is enough to render one suspicious of the reality of any. No period found would satisfy the residuals from the main orbit well enough to warrant its adoption.

Considering the elements of the system as published, the probable error of a single observation is 3.5 km. This is larger than we usually find for good line stars by about 20 per cent.

In the *Astrophysical Journal*, March, 1915, Dr. Schlesinger published a method for determining the periodicity in a series of observations from a consideration of the distribution of the observed velocities. Thus, for example, if we are dealing with a circular orbit, more velocities should be found near positive maximum and negative minimum than near the γ line. If the residuals are due entirely to error of observation the velocities around the γ line will be most numerous. Curves are published giving the expected distribution of the velocities for orbits of various forms. In these curves some allowance has been made for the effect of probable error of measurement upon the results.

Some time previous to the publication of this article the writer tried to make use of the same method in getting a period for the binary 12 Lacertae. In this case the velocities were distributed very much as one would expect if the observed range were due to errors of measurement alone, and yet since the total observed range was over 60 km. there could be no doubt of the binary nature of the star. The conclusion was that the expected distribution was affected very much by errors of measurement. In applying the

method to the present star I have taken some care to find out just what distribution of velocities we should expect when both factors are taken into account.

Let us suppose that we are dealing with a circular orbit whose range is from +10 km. to —10 km., and that the probable error of measurement is *r*. Let the velocities, if there were zero error of measurement, which would lie between the limits +10 to +9, be denoted by *a*, +9 to +8 be denoted by *b*, +8 to +6 by *c* . . . . +2 to 0 by *f*. Let those from 0 to —2 be denoted by *f'*, and so on till those between —9 and —10 are denoted by *a'*. Secondly, let us suppose the range in the observations is due to errors of measurement alone and let the velocities which would lie between the limits 0 to +2 be denoted by *1*, between the limits +2 to +4 by *2*, etc., to infinity. To distinguish the negative from the positive add the subscript minus. Thus 1_- indicates the velocities lying between —2 and 0.

The numbers *a*, *b*, *c*, are easily computed analytically or graphically. The graphical method has the advantage that it can be applied to any radial velocity curve, while the analytic expression for *a*, *b*, *c*, for other than circular orbits is very cumbersome. The values of 1, 2, 3, . . . can be readily computed for any assumed probable error.

Now let all the velocities *a*, *b*, *c*., etc., be operated on by errors of measurement, which errors are distributed as indicated by *1*, *2*, *3*, etc. The product of *a* and *1* (which may be written a_1), will yield velocities lying between +9 and +12, and if we have chosen our interval small enough we may regard the velocities as distributed uniformly within this interval, so that $2/3\ a_1$ will be the number lying between +12 and +10. $1/3\ a_2$ will also lie between the same limits and if we select all these combinations we will obtain the following series as giving the number of velocities between +12 and +10.

$$\begin{aligned}&\tfrac{2}{3}\,a_1 + \tfrac{1}{3}\,a_2 + \tfrac{1}{3}\,b_1 + \tfrac{2}{3}\,b_2 + \tfrac{1}{2}\,c_2 + \tfrac{1}{2}\,c_3\\ &+ \tfrac{1}{2}\,d_3 + \tfrac{1}{2}\,d_4 + \tfrac{1}{2}\,e_4 + \tfrac{1}{2}\,e_5 + \tfrac{1}{2}\,f_5 + \tfrac{1}{2}\,f_6\\ &+ \tfrac{1}{2}\,f'_6 + \tfrac{1}{2}\,f'_7 + \tfrac{1}{2}\,e'_7 + \tfrac{1}{2}\,e'_8 + \tfrac{1}{2}\,d'_8 + \tfrac{1}{2}\,d'_9\\ &+ \tfrac{1}{2}\,c'_9 + \tfrac{1}{2}\,c'_{10} + \tfrac{2}{3}\,b'_{10} + \tfrac{1}{3}\,b'_{11} + \tfrac{2}{3}\,a'_{11} + \tfrac{1}{3}\,a'_{11}\end{aligned}$$

To obtain the velocities lying between +10 to +8 all that is necessary to do is to depress the subscripts by one, $2/3\,a_1$ becomes $2/3\,a_{1-}$, $1/3\,a_2$ becomes $1/3\,a_1$, etc. To obtain the velocities lying between +14 and +12 increase the subscripts by one. The number of velocities lying between limits x and $x+2$ is obtained by increasing the subscripts $\frac{1}{2}\,(x-10)$.

These series have been evaluated for $r=2$, 4, 6.66, 10 kilometers, *i.e.*, for the ratios of probable error of measurement to total range equal 1/10, 1/5, 1/3, 1/2. The results are tabulated below (Table IV), and represented graphically in figure I.

TABLE IV.

Velocities	r = 2 km.	r = 4 km.	r = 6·66 km.	r = 10 km.
from + 0 to 2	·0680	·0753	·0637	·0479
2 to 4	·0795	·0748	·0623	·0474
4 to 6	·0833	·0723	·0591	·0461
6 to 8	·0878	·0674	·0554	·0441
8 to 10	·0793	·0604	·0503	·0415
10 to 12	·0571	·0495	·0442	·0387
12 to 14	·0295	·0380	·0384	·0356
14 to 16	·0104	·0266	·0318	·0321
16 to 18	·0025	·0173	·0258	·0284
18 to 20	·0004	·0099	·0201	·0249
20 to 22		·0053	·0150	·0215
22 to 24		·0024	·0111	·0185
24 to 26		·0009	·0079	·0153
26 to 28		·0002	·0052	·0124
28 to 30		·0001	·0031	·0100
30 to 32			·0019	·0079
32 to 34			·0010	·0061
Sum	·4978	·5004	·4963	·4784

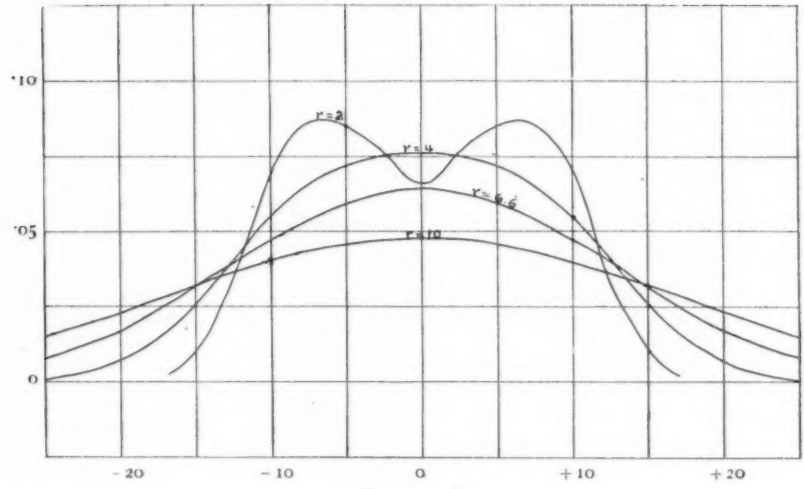


FIGURE 1

GRAPHICAL REPRESENTATIVE OF RESULTS IN TABLE IV.

In the tabulated results the numbers are given to four decimal places, and as each was obtained by the summation of several factors, each of which was only computed to four places, the last figure is not in general correct. The sums of the columns given at the bottom if extended to infinity should total one-half, so that the addition serves as a partial check on the work.

In the curves the abcissae are km., any point $+ x$ indicates velocities lying between $+ x - 1$ and $+ x + 1$ and the corresponding ordinate shows what fraction of all the velocities will lie between these limits. It will be noticed that curves for the ratios 1/2, 1/3, 1/5 are very similar to error curves.

Suppose now we are working with such a binary as the one indicated, namely, a range +10 to —10, and error of measurement r km. Let us suppose, further, that we are unable to get a period, and treat the residuals as errors, how much in excess of the true value of r would the value we obtain be? The results we have

tabulated for the distribution of the velocities enable us to compute this with a fair degree of accuracy, and we obtain that, if $r = 2$ km., the computed r will be 5.1, if $r = 4$ km., the computed r will be 6.1, and if $r = 6.6$ km., the computed r will be 8.2. The computation becomes a little uncertain for $r = 10$ on account of some velocities lying beyond the computed values.

To apply the results to χ Aurigae, we have computed the distribution of the velocities on two bases. In the first the residuals are supposed to be due to error of measurement alone, in the second they are supposed to be due to a probable error of measurement 2.84 km., combined with a binary whose eccentricity is 0 and range 8.52 km. In the table below, the first line gives the distribution of the observed residuals, the second, the computed distribution on hypothesis one, and the third the computed distribution on hypothesis two.

	km. 0—1	km. 1—2	km. 2—3	km. 3—4	km. 4—5	km. 5—6	flm. 6—8	km. 8—10	km. 10—∞
1	14	15	11	14	6	4	11	7	6
2	13	13	12	11	9	8	11	5	6
3	13	13	12	11	9	8	11	6	5

The two hypotheses give almost identical distributions when the number of observed velocities is limited, in this case 88. In other words an inspection of the manner in which the velocities are distributed would not enable us to detect the presence of a velocity variation three times the probable error of measurement.

The above results are deduced for circular orbits only. They have to be modified slightly for orbits of high eccentricity, but in these also the effect of error of measurement is to mask the presence of the orbital variation.

The only evidence that we have of a third body in the system of χ Aurigae is the magnitude of the probable error obtained for a single velocity. If we assume that it should be 2.8, then it would be necessary to assume also a range of 8.5 kilometers in order to obtain a distribution of residuals to agree with the observed.

CALCIUM LINES.

In reducing the measures of the different plates the two calcium lines were not included with the others, for evidence was found showing they would yield a smaller range for the curve. After the completion of the orbit as given in the preceding pages, the velocities from the *H* and *K* lines were grouped into ten normal places as follows: (Table V.)

TABLE V., NORMAL PLACES FOR *H* AND *K* LINES.

	Julian Day	Phase from Final T.	Vel.	Wt.	O—C
1	2420104.4	129.8	—9.5	1.0	—2.3
2	151.3	176.7	—0.8	0.8	+2.5
3	202.4	227.8	+0.5	0.9	—0.4
4	249.9	275.3	+7.8	1.0	+3.2
5	277.0	302.5	+5.2	1.3	—0.9
6	302.9	328.3	+10.3	1.2	+2.8
7	411.8	437.2	+9.9	1.3	—0.6
8	473.4	498.8	+7.2	1.4	—1.9
9	502.1	527.5	+7.2	1.4	—0.1
10	571.2	596.6	+0.6	1.5	+0.7

Preliminary elements to satisfy these places were selected, the period, eccentricity and ω were taken as previously found for the other lines. A solution was carried through for γ and K with the following result:

$$\gamma = +1.5 \text{ km.} \pm 0.46$$
$$K = 10.47 \text{ km.} \pm 0.85.$$

The radial velocity curve for the *H* and *K* lines is given on the same diagram (Fig. 2) as that for the other lines and is drawn with the finer line. The difference between the velocity of the system obtained from the *H* and *K* lines on the one hand and the rest of the lines on the other would disappear if the assumed values of wave-lengths for the calcium lines were increased 0.022 tenth-meters.

The behaviour of the calcium lines in stellar spectra has been a subject for much speculation and investigation since the orbit of δ Orionis was published by Hartmann[1]. The chief facts so far brought out may be condensed as follows:

[1] *Astrophysical Journal*, Vol. XIX., p. 268, 1904.

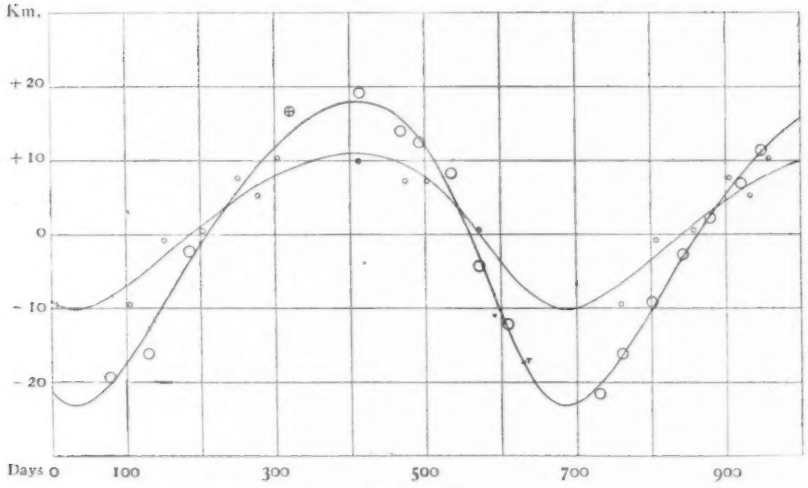


FIGURE 2

RADIAL VELOCITY CURVES OF χ AURIGÆ

1. In eight stars the calcium lines are constant or nearly so and are sharp and narrow, while the other lines are more or less diffuse and show a large range in velocity. These stars are given below.

Name	R.A. 1900		Type	Range of Broad Lines	Remarks
	h	m		km.	
o Persei	3	38·0	B_1	224	Lick Observatory Bulletin 181
η Orionis	5	19·4	B_1	290	" " " "
ψ Orionis	5	21·6	B_2	288	" " " "
δ Orionis	5	26·9	B	216	" " " "
νν Orionis	5	28·5	B_1	264	P. A. O., Vol. III., No. 21.
θ_2 Orionis	5	30·5	B_1	220	Lick Observatory Bulletin 181
β Scorpii	15	59·6	B_1	251	P. O. A., Vol. II., No. 14.
Boss 6142	23	51·0	*Oe p*	230	This JOURNAL, Vol. X., p. 297

All the stars in this list are of type *B*2 or earlier, and moreover if we form a list of all such stars whose orbits have been determined and the *K* line measured we find only one, *ν* Orionis,

showing a lafge range and not included above. Future orbits may add other exceptions.

2. In several stars, the calcium lines are known to vary differently from the other lines and in four cases, orbits have been determined from the *H* and *K* lines, *i.e.*, ξ Persei[2], type *Oe* 5; 9 Camelopardalis[3], type *B*; χ Aurigae, type *B*1; 12 Lacertae[4], type *Oe* 5. In the last two the amplitude is probably about one-half as large for the calcium lines as for the others. There can be little doubt but that future investigation will reveal all gradations from those in which the *H* and *K* lines are constant to those where they have the same oscillation as the other lines.

3. In three stars the calcium lines are sharp and narrow and are shifted about one-half an angstrom unit to the violet. These stars are,—ξ Persei, type *Oe* 5; ϕ_1 Orionis[5], type *B*; ρ Leonis[6], type *B*. There is evidence in these cases that it is the hydrogen and helium lines that are shifted to the red and that the calcium lines may be in their normal positions.

In ξ Persei, the hydrogen and helium lines are broad and no orbit has been determined from them, although they seem to show a large range. The mean velocity is about +65 km. An orbit has been determined from the *H* and *K* lines and the velocity of the system is +15 km. The component of the solar motion away from this star is about +6 km., so that unless the star has an abnormally high velocity for an early *B* type star we must regard the *K* lines as giving the true velocity of the star.

In the case of ϕ_1 Orionis, no orbit has been published, but if we take the mean of the velocities as representing final values, the calcium lines give +19, the hydrogen and helium lines +40, as compared with a computed velocity from the solar motion +15. Here again it is the velocity from the *H* and *K* lines that seems the most probable.

[2] Dominion Observatory *Publications*, Vol. I., p. 338.

[3] *Astrophysical Journal*, Vol. XXXVII., p. 1, 1913.

[4] Journal Royal Astronomical Society of Canada, November, 1915.

[5] *Astrophysical Journal*, Vol. XXX., p. 63, 1909.

[6] Dominion Observatory *Publications*, Vol. I., p. 337.

No orbit has been published for ρ Leonis, but the mean velocities are, for the calcium lines +10, for the other lines +43, for the solar motion +5.

4. In several stars (κ Cassiopeiae[7], type *B*; 9 Camelopardalis, type *B*; ϕ_1 Orionis[8], type *B*), the calcium lines are sharp and the other lines diffuse, but there does not seem to be much difference between the mean velocities as derived from the two sets of lines. The difference between these stars and those in **3** is only one of degree.

5. In many stars of early *B* type, all the lines are very diffuse and in some cases the spectrum is almost continuous, so that little can be said concerning the behavior of the calcium. α Virginis and δ Scorpii are representative.

6. There seems to be no exception to the rule, that when the calcium lines are sharp and narrow and the other lines broad, the star exhibits a variable radial velocity.

Three theories have been advanced to explain the observations. In the first the calcium lines are supposed to be due to masses of cooler gas between the observer and the binary. In the second the gas is supposed to surround the star or stars, and in the third the phenomena are ascribed to anomalous dispersion.

The first hypothesis accounts for the sharp and narrow character of the *H* and *K* lines in class 1 and the fact that they yield constant velocity. Why should the calcium clouds always lie in front of a star of type *B2* or earlier? We have examined several later *B* type stars without finding any where *H* and *K* are stationary. There may be some stars later than *B2* discovered which will show the effect, but the phenomenon seems to be one connected with early spectral type. In all cases in class 1 the velocities yielded by the calcium lines is very near the velocity of the system. This fact, however, does not argue strongly either against or for the first hypothesis on account of the very low velocities of

[7] Unpublished result (Harper).

[8] *Astrophysical Journal*, Vol. XXIX., p. 235, 1908.

the early *B* type stars. The stars given under 3 require an explanation for the hydrogen and helium lines rather than for the calcium. The phenomenon is too complex to be accounted for by an hypothesis which allows so little latitude for adjustment.

The second hypothesis may be presented as follows:—

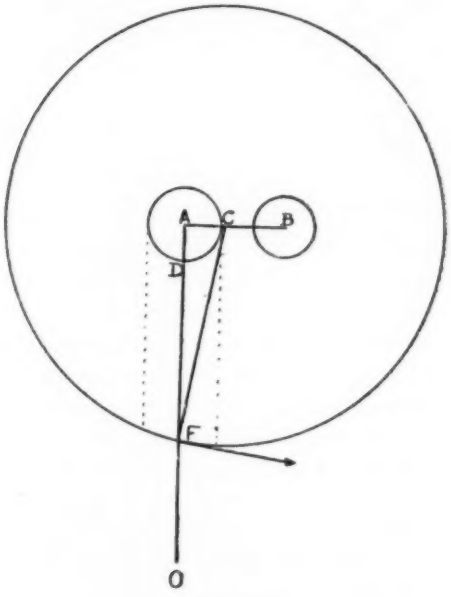


FIGURE 3

Let *A* and *B* (Fig. 3) be two stars or the two nuclei of a binary, and let the gases be condensed about these. It is known that calcium occurs at very high levels, and let us suppose that the equidensity layers in the calcium vapor about the two stars are nearly spheres. The calcium cloud will rotate about the common centre of gravity of the two stars in the same period as they revolve about each other. If *A* is the primary star and only one set of lines is observed on the plate, we need concern ourselves only with the light

from *A*. The light from the photosphere gives the continuous spectrum, and as it passes through the cooler gases hydrogen, helium and calcium, has lines from these elements absorbed. The absorption of the calcium takes place where the element is very rare, which accounts for the narrow character exhibited by these lines. The absorption of helium and hydrogen must be supposed to take place at a much lower level. Assume that it is permissible to speak of effective levels at which this absorption occurs, at a height *D* for the hydrogen and helium and at a height *F* for the calcium. At the time when the primary is moving toward us with the greatest velocity the points at which the calcium absorption is taking place are rotating then as always about the point *C* and so are moving nearly across the line of sight. Moreover, the different points are all moving at about the same rate toward the observer, thus maintaining the narrow character of the lines. The points at which the hydrogen and helium absorption occurs exhibit a wide range in velocity and give the wide character of the lines and the high range if the inclination is nearly zero. If the inclination is nearer to ninety degrees the hydrogen and helium lines would be sharper and give a smaller range. This fits the case of 12 Lacertae and χ Aurigae. There are doubtless other factors not understood which may contribute to the width of the lines observed in other cases. If the calcium cloud were extensive enough the calcium lines would remain nearly stationary, at least the amplitude would be small enough to be masked by errors of measurement. As the cloud condensed, the amplitude observed in the *H* and *K* lines would increase, the exact range depending on the degrees of condensation of the calcium.

This theory is capable of considerable adjustment[9] to meet varying demands and suggests future types of variations that should be discovered.

The third hypothesis ascribes the wide character of the lines in these stars to anomalous dispersion effects. The calcium lines are sharp and narrow, due to the small traces of these elements

[9] See *Astrophysical Journal*, Vol. XXXVII., p. 1, 1913.

existing in the star's atmosphere. It is not intended to pass on the merits or demerits of this theory, but the fact that it does not satisfactorily account for the periodicity in the radial velocities has prevented its receiving wide acceptance.

SUMMARY.

1. An orbit has been determined from 88 measures of radial velocity of χ Aurigae.

2. The amplitude shown by the calcium lines is about one-half that for the other lines of the spectrum.

3. An analysis of the different cases so far known where the calcium lines behave differently from the other lines shows that the phenomenon is one of type and is best explained by the presence of calcium in a cloud surrounding the binary. The absorption of calcium takes place at a much higher level than that of the other elements.

4. The residuals given from the simple elliptic orbit were examined to ascertain if there might be a third body present. No secondary period was found, but the star should be observed with higher dispersion to test this point further.

5. The method of detecting periodicity in a set of observations from a consideration of the distribution of the velocities was tested. The value of this method is greatly interfered with by the effect of errors of measurement. If the ratio of error of measurement to range in the binary is as great as one-fifth, the resulting distribution of velocities is very much the same as would result from errors alone. If the ratio is as large as one-third, the distribution is almost identical. It is in these very cases that the method is most likely to be needed.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
April 11, 1916.

NOTE ON
THE SPECTROSCOPIC BINARY 12 LACERTÆ

By Reynold K. Young

THE elements of 12 Lacertæ were published by the writer in this Journal, November, 1915, and in more detail in the *Dominion Observatory Publications*, Vol. III., No. 3. An examination of the velocities given, shows the K' line to have a smaller range than the other lines in the spectrum. If the calcium lines alone had been used the amplitude of the curve would have been about one-half that deduced from the lines for the other elements.

In the following table the differences between the velocities as given by the K' line and those given by the other lines are grouped according to phase. The period is divided into four parts. The first column includes the positive maximum and the third the negative minimum. The second and fourth include the zero axis of the system.

The weighted mean of all the residuals is positive, due to the value of the wave-length of K' used. If we remove this effect the resulting means for columns 1, 2, 3, 4 would read − 7·3 km., − 0·4 km., + 7·6 km., + 1·4 km. The semi-amplitude of the velocity curve found for all the lines was 16·92 km. The amplitude for the K' line would be about 7½ km. less.

Plate No.	Difference in km.	Plate No.	Difference in km.	Plate No.	Difference in km.	Plate No.	Difference in km.
5670	− 12·0	5642	− 4·4	5623	+ 7·3	5630	+ 1·4
5735	− 22·5	5720	+ 5·5	5692	+ 7·5	5680	+ 3·0
6244	− 3·0	5800	+ 6·9	5728	+ 5·7	5711	+ 1·3
6276	− 0·9	6198	+ 12·4	5792	+ 8·9	5787	− 4·1
6328	− 3·9	6335	+ 13·7	6270	+ 7·9	6262	+ 17·1
6369	+ 5·3	6349	− 16·2	6281	+ 1·8	6291	+ 19·4
6409	− 9·9	6504	− 2·9	6342	+ 8·6	6308	− 2·6
6426	− 4·2	6992	− 2·0	6531	+ 6·1	6356	+ 11·0
6497	− 2·4	6998	+ 3·8	6542	− 4·1	6454	− 5·4
6521	+ 12·6	7033	− 9·4	7001	+ 14·8	7023	− 8·1
6557	+ 0·4	7043	+ 11·9	7020	+ 14·2	7178	+ 0·3
7026	− 1·9	7183	+ 9·9	7177	+ 22·5	7210	+ 16·0
7176	− 13·3	7229	− 4·1	7214	+ 16·9	7244	− 4·4
7182	+ 1·3			7243	+ 5·2		
7201	− 12·2			7251	+ 9·9		
7211	− 9·8			7266	+ 6·7		
7249	− 2·3			7270	+ 15·0		
7268	+ 4·1			7293	− 2·2		
7302	− 2·5			7300	+ 10·0		
7310	− 16·8			7313	+ 28·4		
7314	− 11·0						
Mean	− 5.2	Mean	+ 1·9	Mean	+ 9·7	Mean	+ 3·5

Dominion Astronomical Observatory,
Ottawa, Canada.
June, 1916.

ORBIT OF SPECTROSCOPIC BINARY 125 TAURI

By J. B. Cannon

THIS star, $\alpha = 5^h\ 33^m$, $\delta = +\ 25°\ 50'$, was announced a binary by O. J. Lee (*Astrophysical Journal*, January, 1914,) from the measures of 3 plates (Table II.) giving a range of 62 km. The type is *B3*, the lines being, on the whole, rather poor. Table I. gives the lines measured with the wave-length and the elements to which they are due.

TABLE I.

LINES MEASURED

λ	Element	λ	Element
4481·400	Mg	4101·890	H
4471·676	He	4026·352	He
4388·100	He	3970·177	H
4340·634	H	3933·825	Ca
4267·307	Fe		

TABLE II.

MR. LEE'S OBSERVATIONS

Date	Julian Day	Phase	Velocity	O − C
1911				
December 3	2,419,374·748	17·701	+ 13	+ 10·6
1912				
December 10	747·733	0·590	+ 63	+ 10·2
December 30	767·656	20·513	+ 1	− 1·4

The determination of the elements of the orbit is based on the measures of 79 plates (Tables III. and IV.). These 79 plates were grouped into 14 normal places (Table V.) and the best curve possible drawn through these.

TABLE III.

OTTAWA OBSERVATIONS

Plate	Obs.*	Date	Exposure	Julian Day	Phase	Velocity	Wt.	O − C
		1914	m.					
6608	H	Dec. 6	60	2,420,473·861	2·254	+ 43·6	3	+ 5·1
6618	P′	" 11	65	478·783	7·266	+ 20·9	2	+ 0·5
6630	H	" 15	66	482·785	11·178	+ 7·6	1	+ 0·6
6640	P′	" 16	70	483·830	12·223	+ 13·1	1	+ 7·3
6644	Y	" 17	60	484·764	13·157	+ 8·7	2	+ 3·7
6669	Y	" 30	65	497·682	26·375	+ 20·3	4	− 6·3
		1915						
6681	C	Jan. 4	65	502·800	3·329	+ 25·3	2	− 5·2
6687	Y	" 5	75	503·696	4·225	+ 22·6	4	− 2·4
6694	C-P′	" 8	65	506·737	7·266	+ 25·1	3	+ 10·5
6703	Y	" 10	60	508·634	9·163	+ 21·6	4	+ 11·4
6709	Y	" 12	82	510·659	11·188	+ 7·7	4	+ 0·7
6721	C	" 20	85	518·668	19·197	+ 13·4	3	+ 11·4
6735	C-P′	" 25	70	523·701	24·230	+ 6·8	1	− 1·4
6743	P′	" 27	60	525·639	26·168	+ 25·4	2	+ 1·0
6749	H	" 28	80	526·665	27·194	+ 27·6	4	− 11·6
6759	C	" 29	85	527·692	28·221	+ 44·0	2	− 8·8
6767	C	Feb. 3	60	532·649	5·314	+ 24·3	3	+ 3·8
6784	C	" 12	80	541·694	14·359	− 0·4	1	− 4·4
6789	H	" 17	64	546·644	19·309	− 2·0	2	− 4·0
6797	H	" 18	60	547·570	20·235	− 3·1	3	− 5·3
6807	C	" 19	55	548·616	21·281	+ 3·9	1	+ 1·1
6813	Y	" 21	55	550·542	23·207	+ 23·3	2	+ 17·9
6828	H	Mar. 3	55	560·604	5·505	+ 7·9	2	− 12·1
6836	H	" 4	60	561·596	6·397	+ 4·1	1	− 12·7
6843	Y	" 7	60	564·528	9·329	+ 17·4	2	+ 7·4
6860	P	" 13	70	570·667	15·568	+ 5·8	2	+ 2·4
6869	H	" 15	59	572·600	17·501	− 2·4	3	− 4·8
6875	H	" 18	46	575·584	20·385	+ 11·1	3	+ 8·7
6880	Y	" 19	60	576·601	21·402	+ 15·3	2	+ 12·3
6890	H	" 24	57	581·515	26·316	+ 10·3	3	− 15·2
6913	H	Apr. 8	57	596·584	13·521	+ 6·5	2	+ 2·7
6920	Y	" 13	56	601·578	18·515	− 5·5	2	− 7·5
7248	H	Sept. 14	47	755·908	5·661	+ 11·4	2	− 7·6
7263	P″	" 17	60	758·816	8·569	+ 13·6	1	+ 2·2
7279	H	" 21	63	762·853	12·606	+ 10·3	3	+ 5·0
7287	C	" 22	75	763·852	13·605	− 0·2	1	− 4·8
7298	H	" 28	63	769·832	19·585	+ 1·4	3	− 0·8
7307	C	" 29	58	770·896	20·649	− 6·4	3	− 8·8
7335	C	Oct. 11	80	782·753	4·642	+ 13·8	1	− 9·4
7339	H	" 12	65	783·928	5·817	+ 30·6	2	+ 12·0
7346	C	" 15	71	786·868	8·757	+ 21·3	2	+ 9·9
7363	Y	" 24	70	795·840	17·729	+ 4·3	2	+ 1·9
7367	H	" 26	60	797·799	19·688	+ 0·9	1	− 1·3
7382	C	Nov. 6	60	808·729	2·754	+ 22·8	1	− 20·2
7389	C	" 7	65	809·686	3·709	+ 20·3	2	− 7·7
7390	C	" 7	60	809·729	3·754	+ 28·9	1	− 0·1
7402	H	" 12	75	814·794	9·834	+ 23·5	2	+ 14·5

TABLE III.

OTTAWA OBSERVATIONS — (*Continued*)

Plate	Obs.*	Date	Exposure	Julian Day	Phase	Velocity	Wt.	O – C
		1915	m.					
7407	Y	Nov. 13	60	2,420,815·809	10·849	+ 9·7	2	+ 2·1
7416	C	" 17	80	819·669	13·694	- 0·4	2	- 5·0
7432	H	" 25	70	827·635	21·660	+ 23·1	2	+ 20·0
7442	C	Dec. 3	60	835·712	1·873	+ 39·5	3	- 2·7
7443	C	" 3	64	835·759	1·920	+ 46·2	3	+ 4·0
7445	C	" 3	65	835·869	2·030	+ 32·4	1	- 9·0
7459	H	" 28	58	860·702	26·863	+ 36·1	2	+ 1·6
7460	H	" 28	65	860·744	26·905	+ 33·0	2	- 1·5
7462	C	" 29	60	861·760	27·921	+ 53·2	3	+ 2·4
7463	C	" 29	50	861·799	27·960	+ 52·7	4	+ 1·9
7464	H	" 30	60	862·541	28·702	+ 49·6	3	- 2·2
7465	H	" 30	60	862·583	28·744	+ 52·0	2	+ 0·2
		1916						
7470	C	Jan. 3	70	866·576	4·873	+ 16·5	2	- 5·5
7471	C	" 3	60	866·622	4·919	+ 15·8	1	- 6·2
7476	C	" 7	60	870·562	8·859	+ 9·9	2	- 1·0
7477	C	" 7	60	870·604	8·901	+ 9·2	1	- 1·7
7490	C	" 19	60	882·559	20·856	- 0·3	1	- 2·7
7495	Y-C	" 28	60	891·620	2·053	+ 36·2	3	- 4·8
7496	C	" 28	67	891·669	2·102	+ 26·4	4	- 14·6
7509	P	Feb. 19	58	913·522	23·955	+ 12·3	4	+ 4·8
7511	Y	" 20	70	914·501	24·934	+ 22·9	4	+ 10·9
7514	Y	" 20	64	914·644	25·077	+ 22·0	3	+ 9·0
7515	H	" 21	124	915·528	25·961	+ 8·2	3	- 13·2
7516	C	" 23	60	917·500	27·933	+ 48·7	4	- 2·1
7545	H	Mar. 16	165	939·547	22·110	+ 15·7	4	+ 12·3
7547	Y	" 17	60	940·503	23·072	- 1·8	3	- 7·0
7556	Y	" 19	60	942·507	25·076	+ 12·3	3	- 0·7
7564	Y	" 21	38	944·593	27·162	+ 39·8	2	+ 15·8
7570	H	" 23	60	946·573	29·142	+ 44·6	2	- 4·2
7609	P	Apr. 12	24	966·547	21·252	+ 12·3	3	+ 9·3
7614	H	" 13	60	967·594	22·299	+ 10·7	2	+ 6·8
7616	P	" 19	74	973·547	28·252	+ 64·9	4	+ 11·9

*P = J. S. Plaskett. H = Harper. Y = Young. P′ = Parker.
P″ = H. H. Plaskett. C = Cannon.

TABLE V.

NORMAL PLACES

No.	Julian Day	Phase	Velocity	Weight	O – C
1	2,420,852·514	1·957	+ 39·8	1	– 2·1
2	661·557	3·103	+ 27·6	2	– 4·5
3	711·496	5·036	+ 19·4	1	– 2·1
4	603·354	6·374	+ 18·4	1·3	+ 1·6
5	695·533	9·120	+ 18·1	1·5	+ 7·7
6	580·109	11·231	+ 8·9	1	+ 1·7
7	685·444	13·217	+ 6·0	1	+ 1·0
8	624·063	16·619	+ 1·4	1	– 1·2
9	639·685	19·891	+ 1·8	2·5	– 0·3
10	847·908	22·114	+ 12·8	2·5	+ 9·2
11	761·936	25·676	+ 17·4	2·5	– 0·8
12	743·874	27·064	+ 32·8	1	– 5·4
13	827·528	0·119	+ 50·2	1·5	– 1·4
14	918·193	0·762	+ 54·7	1	+ 2·4

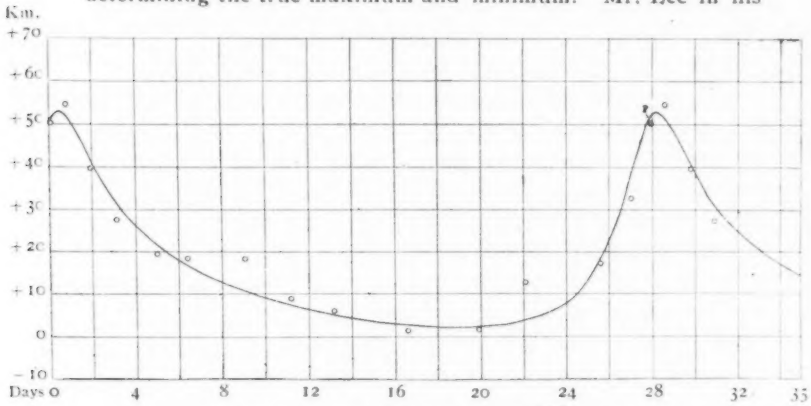
This curve was determined graphically by successive trials. The elements are :

$$P = 27{\cdot}864 \text{ days}$$
$$e = {\cdot}55$$
$$\omega = 335°$$
$$K = 25{\cdot}5 \text{ km.}$$
$$\gamma = +14{\cdot}8 \text{ km.}$$
$$T = 2{,}420{,}471{\cdot}607 \text{ J.D.}$$
$$a \sin i = 8{,}160{,}000 \text{ km.}$$

It will be seen that the residuals are unusually large and that the form of the curve which would go through or approximately through all the normal places would suggest the results of blends. Starting at phase 1 (on curve) it will be seen that the residuals become negative and continue so until about phase 6 days when they become positive. They remain positive until about phase 14 days.

The similar feature is marked in the up-curve. This would be the effect of a blended spectrum caused by the light of the second body of the system if its spectrum were affecting the lines of the spectrum of the primary. It is impossible to say whether

the curve given is low enough at the minimum or high enough at the maximum. Although, on some three or four plates one or two lines show a suspicion of doubling, there are none clearly enough defined to measure, so that there is no possible means of determining the true maximum and minimum. Mr. Lee in his



RADIAL VELOCITY CURVE OF 125 TAURI

announcement of the three measures referred to above, describes the lines as "simple," although one of his plates is taken at the maximum of the curve.

The lines of the spectrum, although not good at all, should allow of much closer measurement than the residuals indicate, and the blend theory seems the only one that would explain the regular variation of the residuals of the normal places. Similar affects have been found in systems where the secondary has been measurable at the maximum and minimum.

No least squares solution was applied as any effect the solution might have could hardly serve to approach nearer the true elements than those arrived at graphically. On account of the probability of blends affecting the velocities of the plates, no probable error was computed for either normal places or individual plates.

DOMINION OBSERVATORY,
OTTAWA, CANADA.
June 29, 1916.

PRINCE BORIS GALITZIN.

By Otto Klotz.

ON the 17th July, I received official word from the Imperial Academy of Petrograd of the death at 4/17th May of Prince Galitzin. It came as a great shock, for he had only reached his 54th year. My acquaintance with him dates from 1907, when we were both delegates at the first general meeting of the International Seismological Association at The Hague. On a similar occasion we were together for a week at Zermatt in 1909, and again at Manchester in 1911, when he was elected president of that association, and as a compliment to him it was decided that the meeting for 1914 be held in Aug.-Sept. in St. Petersburg, and I was on my way thither when the war stopped further progress. Since 1907 we have been in correspondence with each other on matters pertaining to seismology, that new science of which he became so conspicuous an ornament. As a scientist Galitzin was many-sided, but my personal contact is confined to that of seismology. Like many other cultured Russians he spoke, besides his mother tongue, English, French, and German fluently, in fact, his address in English at the Fifth International Congress of Mathematicians at Cambridge in 1912 aroused the admiration of the English for its purity of diction and fluency of delivery.

Galitzin traced his ancestry back to the 14th century, being descended from the princes of Lithuania—the Jagello line—which played an important part in the history of Poland. At the time of his death he was a member of the Imperial Academy of Sciences at Petrograd, which in itself shows the eminence he had attained in Russia, and this eminence was international; and President of the Seismological Commission of Russia.

For the past 15 years he had thrown his energy and ability into the study of seismology, theoretical and practical. He per-

fected a seismograph, in which he introduced galvanometric registration, and magnetic damping—a radical innovation in seismographs. His activity is shown by the many papers he published, issued by the Academy and Earthquake Commission, the latter created through his instrumentality. As a result of the latter there have been established throughout the Russian Empire, six first class stations, all provided with his sensitive seismographs, and many second class stations, so that as far as highly efficient governmental stations are concerned, Russia leads the world, and all due to Galitzin. He was the first to show that with his seismograph not only the distance of an earthquake was obtainable, which is the case, too, with other good instruments, but also the direction within fair limits; so that one instrument practically suffices for the location of an earthquake. The results of his many researches and studies in seismology were given in a course of 89 lectures at the Imperial Academy, and these were published in a volume, "Seismometrie," in 1911. A German and revised edition was issued by Professor Hecker in 1914, which is one of the most important contributions in the whole literature of seismology. The last communication we had from him was his valuable contribution to the *Comptes Rendus* in 1915, Tome 160, p. 810, being an evaluation of the Pulkowa seismogram in terms of C. G. S. for the Pamir earthquake of Feb. 18, 1911, and of which an account was given in the November number, 1915, of this JOURNAL.

I regret that this brief note is so inadequate and fails to do full justice to Galitzin; at the same time I could not allow the loss to science and particularly to seismology that the death of Galitzin has occasioned, to pass in Canada unnoticed, and hence this record for the JOURNAL.

Prince Boris Galitzin was a star of the first magnitude.

DOMINION OBSERVATORY, OTTAWA,
July 19, 1916.

COMPANIONS OF THE SUN.

By Albert D. Watson

LIMITED to a narrow physical environment, we have developed what may be termed a physical consciousness. Even the blaze of the stars, that jewels night with a serene beauty challenging word pictures in vain, deceives us with a nearness which is only apparent. The earth seems solid enough and even the heavens appear to be within reach. A child thinks that with a long ladder, he might climb up into the sky and shovel the snow down. We are all near children, and it is hard for any of us to realize with one of the oldest writers of the race that "He stretcheth out the north over the empty place and hangeth the earth upon nothing." Yet the solid earth which serves us for a foundation has itself nothing solid on which to rest, but like all the other companions of the sun, is suspended in space by cables of law. If our earth-mother did not hold us closely to her bosom we should ourselves fly out of her arms and become prodigals like many another piece of free and independent world-stuff.

We cannot see the solar system whole. Being a part of it ourselves, while we look at a second part, a third part is behind us. Those companions of the sun seen by us at any time are strewn over the wide ceiling of space and mixed with the stars. It is clear, therefore, that we can see the solar system only ideally.

Finding oceans of space on all sides of us, we are at first overawed by the sense of our own utter insignificance. We seem almost lost in the universal immensity. Our thought is plunged into interminable deeps. Nevertheless, we too are composed of star-stuff, and are essential parts of the whole cosmos. Even a child may say from the vantage of the soul view:

"The open heavens are too small to contain me,
I contain them."

NOTE--The numbers in this article, though only approximate, are reasonably accurate.—A.D.W.

Let us, then, try to see the solar system as clearly as if there were nothing else in the heavens, and we looking on it from the outside. The unwearied endeavors of countless investigators, toiling through innumerable years, despite inconceivable difficulties and discouragements, enable us to get an accurate conception of what the solar system would look like if we could see it alone and see it whole.

Imagine then, a great wheel of worlds with a hub more than six hundred times as large as the combined volume of all the orbs that encircle it. This sun-hub is brilliant, blazing, colossal. Jupiter with his nine moons or Saturn with his ten moons and his rings, is but a toy in comparison with this almost inconceivable pageant. The zodiac is the rim of this vast wheel, and we of this little earth are in the plane known as the ecliptic plane, because here all the eclipses seen by us take place.

Looking at this wheel from the outside, yet from the plane of the ecliptic, it would resemble a long line of orbs extending over 6,000,000,000 miles, with the sun blazing in the centre. The sun's diameter is about as one mile in seven thousand of the length of this line of sun-companions. This makes the sun seem comparatively small. Yet if our moon had a satellite revolving in the ecliptic plane at a distance of 190,000 miles, it would be possible for the earth to stand at the sun-centre and our moon could revolve around the earth, and the satellite of the moon could revolve around it, and all would still be far within the circumference of the sun.

If our eye were placed above the plane of the ecliptic, we should see the solar system as an ellipse somewhat after the appearance of Saturn and his rings at the present time. As our eye rose higher above the ecliptic plane, the smaller diameter of this ellipse would increase till finally it would be a near circle.

The companions of the sun comprise eight planets, twenty-seven moons, hundreds of comets, and thousands or even millions of meteors and tiny particles of world-stuff, all floating along with the great household of the sun. They may be classified as follows:

1. The major planets and their moons.
2. The minor planets.
3. The comets and meteors.

All these bodies are moving around their primaries in elliptical orbits.

Of the eight major planets, the four nearest to the sun are much smaller than the others, indeed, they are as to their size, pretty well within the class of large moons. Mercury, Venus, and Mars are quite perceptibly phased to our vision, whereas the larger, outer four, owing to their comparative distance from the sun, are free from any perceptible phasing. The two innermost planets, Mercury and Venus, are without moons, being exceptional in this respect; indeed, they may themselves almost be regarded as moons, since they turn always the same face sunwards. This coincidence of rotation with the revolution periods obtains in the case of all the moons where, in the nature of the conditions, such a coincidence is determinable. (See Bulletin No. 64, Lowell Observatory.)

The solar system is the unit of group astronomy. There are probably, in other solar systems than ours, bodies with characteristics not represented in our group, but on the whole, the system in which we live is a good example of the family of a star. The unit of distance within our sun-family is the distance of our earth from the sun, which is roughly 93,000,000 miles. It is known as a *sun distance*. Out in the general star-fields the unit of distance is the space covered in one year by a light-ray, and is called a *light-year*. This amounts to over five trillions of miles, or over 60,000 sun-distances. The star nearest us, so far as we have been able to ascertain, is Alpha Centauri at four and two-fifths light-years distance from us.

Here, then, is our solar group or star family moving on in space at a rate of nearly 12 miles per second, its individual orbs all the while revolving, rotating, librating, describing polar circles in the sky, and acting like a group of gyroscopes held together

by chords of infinite harmony, and marching to the music of the morning stars.

Mercury is three-eighths of a sun-distance from the solar centre, turns always the same face to the sun, and can be seen only when its line to the sun is nearly at right angles with ours. He is too bright to see in much detail. It has been stated that Copernicus never saw Mercury, but apart from its general improbability, there is evidence to the contrary.*

Mercury is the smallest of the major planets. (Diameter, 3,000 miles.) His orbit is inclined at an angle of seven degrees to the plane of the ecliptic, hence he passes between us and the sun only twelve times in a century, whereas if it were coincident with that plane we should have a transit of Mercury at least three times a year.† Two pounds on the earth's surface would weigh but one in Mercury. His axis of rotation is nearly perpendicular to the plane of his orbit, which being very eccentric, produces a season dependent upon his varying distance from the sun. His greatest removal from the sun varies to his least as three to two.

Having no appreciable atmosphere, Mercury is not eligible as a health resort. His year consists of 88 of our days or less than three months. Dividing this year into summer and winter according to his less or greater distance from the sun, each of these periods of about six weeks measures a semi-revolution in his orbit. The coldest hour in winter on the sunward face of Mercury is probably hotter than the boiling point. The hottest hour on the anti-solar hemisphere must be comparatively cool

* Olmstead, in *Letters on Astronomy*, page 230, says: "Copernicus . . . lamented on his deathbed, that he had never been able to obtain a sight of Mercury," but Berry of Cambridge, in *A Short History of Astronomy*, page 95, says: "Copernicus, moveover, points out in more than one place that the high latitude of Frauenburg and the thickness of the air were so detrimental to good observation that, though he had occasionally been able to see the planet Mercury, he had never been able to observe it properly." For a fuller discussion see this JOURNAL, vol. 9, page 264, 1915.

†The next transit of Mercury occurs May 7th, 1924.

and may have been the abode of intelligent beings before its atmosphere was exhausted. If there ever were such beings, they must have kept out of the sunlight. The strongest contrast of Mercury with all the other planets is in the fact that its orbital inclination to the ecliptic plane is three times as great as the average of all the other planets and more than double that of the next greatest which is Venus .

Venus is the earth's nearest neighbor in the sun-family, being two-thirds of a sun-distance from the solar centre. She is about the same size as the earth, and in all probability keeps always the same face sunward. Her year is about seven of our months, and as her axis is perpendicular to the plane of her orbit, which is nearly circular, there are no seasons in Venus. She is a warm planet, but her dense atmosphere moderates the heat. If she turns always the same face to the sun, as appears increasingly probable, this fact bears an interesting relation to the question of the habitability of this planet. The sunward hemisphere would, in that case, be too hot for habitation, and it is possible that the opposite side would be too cold. There is a borderland, which we might name the twilight circle, out of the direct sunrays, yet not entirely dependent upon starlight, where it is reasonable to suppose that habitation may be quite feasible.

Owing to the inclination of her orbit of three-and-a-half degrees to the ecliptic plane, Venus transits the sun only at intervals of eight and 122 years alternately. Venus is never seen from earth at midnight, as her elongation or distance from the sun east or west never exceeds 45 degrees. She is often seen by daylight, especially in an intensely blue sky when a cloud passes over the sun. It is very important to know exactly where to look, though some have seen it when not looking for it.* Venus when brightest has about twelve times the brightness of the most brilliant fixed star.

* In a letter from a friend, dated Muskoka, Aug. 20th, 1909, at 12.18 p.m., the following observation is reported: "About four minutes ago, I was watching a tiny cloud-craft sailing high in the east, far from any other clouds. I watched it till it was absorbed in the blue. Then, my

eyes, dropping a little lower, beheld—Venus, yes, Venus, and the sun shining! I think there must have been a slight veil over the sun, for I looked away from Venus for about a minute, and when I looked back, I could not see her. The sky had become an intenser blue, and the sunshine seemed brighter. There are now some clouds floating in that part of the sky. I shall try to see her again before I go in to lunch. 12.41—Had quite a time finding her again. Watched her till a huge cloud that had partly obscured the sun covered her." A.A.E.

We have little likelihood of ever finding evidences of life on Venus, but the Venutians, if there be any, may find our planet a most interesting and easy object of telescopy. The relations in this respect are the reverse of those with the hypothetical Martians. As the face of the earth as presented to Venus is about four times as large as that which Mars presents to us, we may be sure that the people of Venus, with means of scrutinizing the heavens similar to ours, could see far more of our life than we could reasonably hope to see of Mars'. They would have excellent maps of the physical geography of our planet, showing continents, islands, oceans, rivers, mountains, etc. As Venus is a difficult object of observation to us, so also for similar reasons, the earth would be exceedingly difficult of observation from Mars.

Unless clouds obstructed their view, the polar snowcaps of the earth would be readily visible from Venus. As the earth is sometimes 10,000,000 miles nearer to Venus than Mars ever is to us, and has four times the apparent surface presented, the only hindrance to results would be the possible conditions on the surface of Venus. Have they telescopes? Are their clouds too dense? Are there people there at all?

The phases of Venus are most interesting, especially at the period just before her inferior conjunction, when she passes between the earth and the sun. She then has the outline of a new moon, and is most beauiful, appearing as a perfect silver bow. Six pounds on earth would weigh five on Venus.

The Earth is the third planet from the sun. Besides the three motions common to all planets, rotation, revolution, and progress with the sun, the earth has several other motions or

librations due to lunar and near planetary attractions. The axis of the earth points at present to the vicinity of the pole star, but is describing a figure in the heavens which it completes in 25,800 years. The earth has also a magnetic period, and an auroral period, both of which appear to have definite relations with the sun-spot period of our solar centre.

Objects are lighter at the equator than at the poles. Time-recording pendulums have to be shortened for frigid latitudes. This is because the semi-diameter of the earth and also the centrifugal force are greater at the equator than at the poles.

The atmosphere of the earth helps to diffuse the light and mitigate the blackness of the shadows cast by the earth at night. It shields us from the destructive power of meteors, protects us by radiation from extreme heat and cold, and hides the stars in the day time. The blue sky would be black were it not for the atmosphere. Besides these effects, there are many beautiful and interesting phenomena due to the atmosphere. Among these may be mentioned the earth's shadow thrown up as a dim arch in the eastern sky as the sun sinks behind the western horizon. It is seen as a wide-sweeping arch gradually rising in the east awhile after the sun has disappeared. This twilight shadow is much modified by the atmosphere.

Another prenomenon dependent doubtless to a considerable extent upon the density or rarity of the atmosphere is the Aurora. While the frequency and, indeed, the final cause of auroræ are probably to be found in the sun and those disturbances of solar energy related to the sun-spots, there seems to be a state of the atmosphere which is peculiarly suited to their display.

The Moon is the fifth in size among the satellites of our solar system. Three of Jupiter's and one of Saturn's are larger, but ours is the largest of all in proportion to the mass of its primary. It follows the law governing the moons by turning always the same face towards the earth, but owing to a swinging motion, we see in all about four-seventh of its surface. On the moon there is no atmosphere to support life, no water and no weather. There

is no sudden change of temperature in the constant sunlight. That portion of the sphere that receives no sunlight is partially illuminated (except at full moon) by earthshine. The remainder is so black that to go into the moon's night where it is not earth-illumined is to disappear.

As the orbit of the moon is inclined to that of the earth at an angle of five degrees, lunar eclipses which otherwise would occur once in every lunar month, are somewhat infrequent, occurring never more than three times a year. This is obviously when the sun, the moon, and the earth are all in the ecliptic plane, the moon being therefore at one of the nodes where it crosses the ecliptic. Solar eclipses also occur only when the moon is crossing the ecliptic, therefore at new moon as distinguished from lunar eclipses which occur always at full moon. Solar eclipses never occur less than twice nor more than five times a year.

The mountains of the moon are much higher than our terrestrial peaks in proportion to the size of the orb. Accurate measurements are impossible because of the absence on the moon of a sea level from which to measure the heights of the mountains. All that can be done is to measure from the surrounding plane. The highest peak heretofore measured runs up 24,000 feet.

The moon does not perceptibly affect the earth's weather, except to glorify it with a soft, silver light. Our moon is the most beautiful of all telescopic objects, and has been the comrade and conniver with poets and lovers in all ages.

There is accumulating evidence that some of the lunar craters are not yet dead, but there is no animal life and no vegetation on the moon's surface. Six pounds on the earth would weight only about one on the moon.

Mars. Mars is the most easily observable of all the planets from the viewpoint of the earth. We can see the snow-line advance and recede at the Martian poles as winter or summer prevails. His orbit is inclined to the ecliptic plane at an angle of 1° 51′. His axis leans to his orbital plane between 23° and 24°, this being almost the same as that of the earth. His

axial inclination and his orbital eccentricity, which is greater than other major planets excepting Mercury, accentuate his seasonal changes. The atmosphere of Mars is less dense than ours. Five pounds on the earth weigh only two on Mars. Water freezes at higher temperatures. The melting of the snow-caps in a planet where the mean temperature is only minus 36° Centigrade has suggested to some that these snow-caps consist of frozen carbonic acid, but the thinness of the atmosphere admits of rapid seasonal changes of temperature, and it is probable that a comfortable summer with rather cool nights prevails in the Martian tropics.

Mars as seen from the earth varies from one to about seven diameters, therefore, from one to about 49 in area. It is clear then that the most successful observations must be made when the terrestrial aphelion coincides as to date with the Martian perihelion. The opposition of Feb. 9th, 1916, was not a favorable one, since the distance of Mars from the earth was over 62,000,000 miles.

Throughout a long winter of many months, no sunlight falls on one pole, but on the opposite one a midnight sun prevails for a corresponding period. When the planet has reached the opposite segment of his orbit the relation of the poles to the sun has been reversed as is the case in our earth.

Mars has received attention out of all proportion to any astronomical interest attached to the second smallest of the planets. His human interest accounts for this. Is he peopled? If so, do his inhabitants know anything about us? The earth is nearly four times as large, viewed from Mars, as Mars appears to us. But this is offset by the fact that when we are nearest to them, in order to look at the earth they have to look against the sunlight and see only the least crescent of the earth's surface, since its illuminated hemisphere is sunward and the Martians are on the shaded side of the earth and cannot see it at all. They are in relation to us much as we are in relation to our sister planet, Venus.

As to whether there are inhabitants in Mars, we know that

though the mean annual temperature is very low, the sudden changes in temperature would be well understood and could be predicted to an hour with approximate accuracy. The inhabitants could practise a systematic mobility. Migration with the seasons would be as common and as natural in Mars as to lay in coal is to us. If there are inhabitants, they probably adapt themselves by social organization, migration and irrigation to the suddenly changing temperature, water supply, and climate.

It is always summer somewhere on Mars, and summer is probably a pleasant season with cool nights. The air is clear, the skies light-blue, the weather dry. The whole climate is airy and light. To those who desire a startling glimpse of the ingenuity of an alert mind in astronomical fields, and who are specially interested in the processes of such investigations, no more interesting works could be recommended than those of Prof. Lowell, of Flagstaff, Arizona. His books dealing with Mars are unique in that field. One would like to believe the theory of Prof. Lowell, and people this companion world, our nearest brother, no less than our nearest sister Venus, with happy souls who live and love, feel a subtle communion with us and are glad.

The moons of Mars are of great interest. Two have been discovered, Deimos and Phobos. Deimos is probably about 25 or 30 miles in diameter and four Martian diameters from its primary. It revolves around Mars from west to east in 30 hours, but the revolution of the planet in the same direction in 25 hours gives Deimos the appearance of travelling slowly from east to west. Thus if Deimos were a new moon soon after sunset, the next evening at sunset he would still be about five hours up the western sky and would show a considerably developed crescent. He passes through all his phases at each appearance, remaining above the horizon about two days and a half, then disappears for a similar period. He is never seen more than 69° from the Martian equator because of his nearness to the planet. He is frequently eclipsed and often transits the sun.

Phobos is probably only about five miles in diameter, and re-

volves at less than one Martian diameter from the surface of the planet. It completes one revolution in about seven hours, and meets Deimos in the sky (as seen from Mars) at each revolution. It rises two or three times during each night, and almost every night is eclipsed once or twice in Mars' shadow. He is not seen from Mars beyond 35° of latitude north or south. He passes through all his phases each time he crosses the sky. Phobos frequently eclipses Deimos and both moons often transit or partially eclipse the sun. Deimos would darken about one-tenth of the sun's disc, Phobos only about one twenty-fifth. Mars must hold the record for eclipses. About 1,400 eclipses per annum are possible to the credit of Phobos and several hundred more to that of Deimos.

Passing over the minor planets for the present, we have now to consider briefly those four colossal orbs whose paths are far beyond that of Mars. They differ from the smaller major planets, not only in size, but also in constitution. They are much lighter than the smaller planets in proportion to their volume, and are in a much less solid state. Their size has probably prevented rapid cooling. They have a total of 24 moons whereas the four smaller major planets have, in all, only three moons. These four colossal planets include vast areas within their orbits. Neptune, the outermost, being nearly twenty times as far as Mars from the sun. The comparative areas included in their orbits is therefore almost one to four hundred.

Jupiter is far the largest of the planets. (Diameter, 84,000 miles.) It is larger, indeed, than all the others combined. How appropriate that this mighty sphere should have such a name! But is it not strange that Venus, who looks so much brighter, was not in pre-statistical days called Jupiter? Probably Venus was named first because of her greater brilliancy, and in virtue of her conspicuous beauty, received the name of the charming goddess, after which the only name worthy of the great planet we are now considering was that of the father of the gods.

Jupiter resembles the sun and Saturn in the fact that he is

not solid at his surface. His equatorial regions, like theirs, float somewhat freely over the deeper layers of his body. The surface at the equator completes an axial revolution in less time than is required by the polar regions to complete theirs. This may not mean that Jupiter and the sun are slackening their pace. It may be explained by centrifugal forces. Jupiter's axis is perpendicular to his orbital plane, which is inclined to the ecliptic at an angle of only 1°18′.

Seasons are absent from Jupiter's year, which is equal to about twelve of ours. He therefore passes eastward, as seen from earth, through about one zodiacal sign each year. The Jovian day is less than ten hours, or about twenty minutes less than the day of Saturn. Bodies weigh about two and a half times as much as on the earth and twenty per cent, more at the poles than at the equator. Jupiter and the poles of Saturn are the only places in the solar system, away from the sun itself, where bodies weigh heavier than on earth. There are 10,455 days in the Jovian year. A point at the earth's equator moves a little over 1,000 miles per hour, a similar point on Jupiter's equator moves about 26,000 miles per hour.

Jupiter has nine moons. The four largest were discovered by Galileo, being among the very first objects revealed by the aid of the telescope. The latest Jovian moon was discovered in 1914 by means of the photo-plate, the object being too distant and too small to be seen with the largest telescope. This latest discovered satellite moves in an orbit whose diameter is about 32,000,000 miles. Its motion is, like that of the satellites of Uranus and Neptune, apparently retrograde.

The succession of transits, occultations, eclipses, etc., of Jupiter's moons as seen from earth are among the most interesting phenomena an amateur can study and observe. The author of this paper remembers gratefully the excellent three-inch achromatic telescope through which he had a first glimpse of Jupiter and his four great moons, and has almost tender reminiscence of

the little, old gentleman who so graciously afforded him that great pleasure.

Interesting as the Jovian lunar phenomena are, as seen from the earth, they would be much more so if they could be viewed from the planet itself. At present we may but sigh and piously express the hope that some day all that is indestructible in death's tremendous adventure may be clothed in a body so ethereal as to defy all those chemical and physical changes which set barriers here to our complete freedom. If such a faith be well founded, and some of us think it is, we shall then see the beauties of the worlds that are now only ideal, we shall perceive the subtle forces that dwell beyond the violet rays and hear the music of the ultra-tonal harmonies.

From the disparity between the predicted and the observed times of eclipses of Jupiter's moons, a time element was found to exist in relation to the movement of light from one part of the universe to another. Before that, light had been supposed to move to any distance instantaneously, as we have up to the present supposed gravitation to act. Even gravitation has recently been made the subject of question in relation to a time element.

Saturn. It is about 400,000,000 miles from the orbit of the earth to that of Jupiter. Another 400,000,000 miles brings us to the orbit of Saturn, the second largest of the planets. Jupiter is 1,300 times the volume of the earth. Saturn is 770 times the same volume. The body of Saturn (diameter, 73,000 miles) is not yet rigid and its axis is inclined to the plane of its orbit at an angle of 27°. The seasons are well marked in the Saturnian year, but each quarter lasts about seven terrestrial years. Bodies weigh more at the poles of Saturn and less at the equator than on our earth.

The most distinctive feature of this planet is his unique system of rings. These are in the plane of Saturn's moons, with the exception of the outermost moon which is apparently retrograde in motion. The rings consist of meteors. From the centre of the planet to the circumference of its outer ring there are, first,

the 36,500 miles of the radius of Saturn. From the surface of the sphere to the inner margin of the inner ring is 9,000 miles. This, which is known as the crepe ring, is 12,500 miles in width and runs into the middle ring which is 17,000 miles wide. Outside the middle ring is a space of one thousand miles before the outer ring, 10,000 mile wide, is reached.

As Saturn's orbit is inclined to the ecliptic at an angle of 2° 30′ we should always see the Saturnian rings as a linear projection were it not for the inclination of his axis to the plane of his orbit. This leaning towards us of one or other of his poles shows us sometimes the north, at others the south, side of the rings and occasionally at the transition point, the linear configuration is seen. Only the most powerful telescopes will show the rings at all when they lie edgewise to the plane of our vision.

Saturn has ten moons, only one of which (Titan) is larger than ours. The first four, like our own and some of the moons of Jupiter, have been proven to turn always the same surface towards their primary. As no exception to this rule has been found, it is likely that it obtains in the cases of all moons. The ninth moon of Saturn (Phoebe) has technically a retrograde motion.

Uranus and *Neptune*. Nearly 1,000,000,000 miles beyond the path of Saturn is that lone track where Uranus runs his silent course and from which he beckons his farthest frontier signals to our unassisted vision. Thus between the orbits of Saturn and Uranus, the entire solar system as far out as Jupiter and his farthest moon might easily perform all their revolutions. The same may be said of the space between the orbits of Uranus and Neptune. These two planets might well be called the lonely worlds, since each of them is more than ten sun distances from any other planet.

Uranus appears as a faint green star and is 65 times as large as the earth. The spectroscope reveals a substance in the Uranian atmosphere not known to us on earth. Uranus has four moons and Neptune one. They are all smaller than our moon.

These planets and their moons were long supposed to have a retrograde motion, i.e., the planets were supposed to rotate and the moons to revolve in a direction contrary to that usually followed by other moons and planets. It is now thought that the inclination of the planets to the plane of their orbits is more than ninety degrees and that therefore their motions follow the general rule.

Technically speaking, the motions of these planets and moons are retrograde, but an interesting theory is gaining favor which claims that this was originally the direction in which all moons and planets revolved, and that the west-to-east movement was a later development. Ten pounds on earth would weigh nine on Uranus, and a few ounces less on Neptune.

Neptune. The story of how Adams and LeVerrier worked out the position of Neptune mathematically before the planet had as yet been seen, basing their calculations upon the reported deviations of Uranus from his predicted course, is well known as one of the most brilliant achievements in the history of science. In such subtle manner does the human mind come into a real harmony with that unseen Force that swings the balanced worlds. Such vivid and conspicuous results of our investigations of law would almost tempt one, with Pythagoras, to strain the ear and listen for "the music of the spheres." Like Uranus, Neptune has a far-reaching atmosphere.

The Minor Planets. Beyond the orbit of Mars, yet within that of Jupiter, lie several hundreds of bodies, all of them less than 500 miles in diameter, known as the minor planets. The theory has been advanced that these are the fragments of a shattered major planet that has been broken up and scattered in detail throughout this region. The irregular shapes and motions of many of these small bodies seem to support such a theory. The presence of such a planet was long suspected in this region, a fact which lends further support to such an idea.

Certain analogies as to the distances of the respective planets from the sun (Bode's Law) led a number of astronomers at the

beginning of the nineteenth century to suspect the presence of an undiscovered planet between the Martian and Jovian orbits. They instituted a methodical search, but an outsider, Piazzi of Palermo, was the first to discover a new planet. This was named Ceres. Others were soon discovered and named after the classical goddesses till such names were exhausted. Other names have since been used, but resort is now had to numbers, for over 800 of these minor planets have been discovered, catalogued, and marked on the "zodiacal way-bill." They vary in diameter from a few hundred yards to about 500 miles. Only one of them, Vesta, the third largest in size, can be seen by the unaided eye, and then only under the most favorable conditions. Its diameter is about 240 miles.

The orbits of the minor planets are inclined to the ecliptic variously up to 30°. They move in very eccentric orbits. Their combined volumes are not equal to more than one-fourth that of the earth, and it may be far less. Gravity on the surface of such small bodies is quite inconsiderable, and it is believed that a human arm might, even on the largest of them, cast a stone into space so forcibly that it would never return.

The most interesting of all these minor planets is Eros. It is the only one within the orbit of Mars. It approaches the earth more nearly than any other planet, major or minor. Its next nearest approach will be in 1938, when it will be within 13,500,000 miles. It rotates in five and a half hours. Its diameter is probably about twenty miles.

Comets and *Meteors*. Comets are aggregations of meteors, dust and vapor, and meteors are particles of disintegrated comets. Comets are the product of irregular or so-called accidental cosmic action. Meteors are cosmic debris resulting from attractions and repulsions that must be almost constantly active in one or other part of the heavens. The meteors are dead bodies left on the battlefields in the great war of the worlds.

The breaking up of Biela's comet in 1846 is a well-known incident in the history of the subject. The comet returned in two

parts widely separated in 1852, and in 1872 as a meteoric shower which was unquestionably a part of the comet.

Comets and meteors are all probably of solar origin. This theory is strongly sustained by the fact that no element or substance foreign to our system has ever been found in any of these celestial adventurers. So far as has been ascertained, they all move in closed or eliptical courses. The solar system, therefore the earth's atmosphere, is moving constantly in one direction. If comets and meteors were not all of solar origin, they would assail the earth's atmosphere chiefly from that portion of the heavens which confronts it in its onward course. There would at least be a distinct preponderance of these bodies seen from that direction. But no such preponderance is found.

The distinctive features of comets are thus reduced to their peculiar phenomena, and their amazingly eccentric courses. The nucleus of a comet consists of an agglomeration of meteors, the coma, of dust and vapor; and the tail, which is acquired only when near the sun, is the product of radiant and electric energies (acting on microscopic particles) in excess of the force of gravity, thus giving a direction always from the sun. The tail appears only when the comet comes near enough to the sun to be subject to its radiant and electric forces, and disappears when it passes beyond those influences.

The periods of comets—the cometary year—varies from a few months in some cases to thousands of years in others. Their courses reach often far beyond the orbit of Neptune, but no one knows how far some of them go. The lustre of a comet is enhanced if its advent occurs during a maximum sunspot period. therefore, also, during a period of maximum auroral display. The latest appearance of Halley's comet occurred when there was little sunspot activity, and the appearance was disappointing to some. Perhaps it might have been more stupendous had the sun been more active at the time. It is probable that comets and meteors keep always the same face sunward.

Meteors are uncharted masses of adventitious matter floating

in space around the sun. Coming within the earth's influence, they are drawn into its atmosphere, where the friction may melt them and turn them into vapor, or failing complete vaporization on account of their size, they may fall to the ground or into the sea, but in a few cases they pass through a part of the earth's atmosphere and out again into space.

In the case of the meteors of Feb. 9th, 1913, when several groups of large meteors passed over the western hemisphere and the mid-Atlantic ocean, it is not known certainly whether they reached the earth's surface and were lost in the sea, or passed out of the atmosphere and went on their way. The latter is perhaps the more probable theory. They were very large and were observed for some thousands of miles before they disappeared. Their height has been variously estimated at from 25 to 45 miles. They made a distinct sound which took some time to reach the ear because of their distance away. This sound was in most cases not heard till after the meteors that produced them were out of sight. The comparatively slow procedure of these objects across the sky was remarkable, and the whole picture so ably dealt with by Prof. Chant and others in the JOURNAL of May-June, 1913, was one of the most startling and remarkable seen by the eyes of the present generation.

Many specimen meteorites are on exhibition at various centres. They are composed chiefly of stone and iron.

REVIEW OF PUBLICATION

A Voyage in Space; a course of six lectures, "adapted to a juvenile auditory," delivered at the Royal Institution at Christmas, 1913, by H. H. Turner, D.Sc., D.C.L., F.R.S., Savilian Professor of Astronomy in the University of Oxford. Pages xvi. + 304, with over 130 illustrations. London: Society for Promoting Christian Knowledge, 1915. Price 6sh.

This is one of that steadily growing class of scientific books which the general reader peruses with interest and profit and from which the professional scientist may also obtain information of value. As is well known, there is a course of juvenile lectures given at the Royal Institution every Christmas, and ever since they were instituted, nearly ninety years ago, by the illustrious Faraday, they have been a very attractive feature of the holiday season. The most distinguished scientists have undertaken the course and usually they have gone to great lengths to present striking experimental illustrations.

Professor Turner is one of the most versatile workers and writers in the domain of astronomy and he has spared no effort to present to his audience — not all juveniles, by any means, but including many distinguished persons — a very pleasing story, filled with many literary and historical references and illustrated by all the resources of modern science.

The book contains 300 printed pages, or about 50 to a lecture. The titles of the chapters are: I. The starting-point, our

earth ; II. The length of our voyage and the start through the air ; III. Journeying by telescope ; IV. Visits to the moon and planets ; V. Visit to the sun ; VI. Visits to the stars.

Let me give a short statement of the first lecture. It begins with an account of various attempts to make a voyage in space, passing from Lucian's "Icaromenippus" down to the brilliant attempts of Jules Verne, H. G. Wells and George Griffith. Then in discussing the question, "Is it better to try to believe things people tell you, or is it better to try to find out for yourselves?" an account of Galileo's experiments on gravity is given. To illustrate the dropping of two weights from the Tower of Pisa, a wooden and a leaden ball were dropped from the roof of the building into a box of sand. Then we have a reference to the Cavendish experiment and an account of Tycho Brahe and Kepler, with instructions how to draw an ellipse thrown in, after which is a fuller account of Newton and the law of gravity, including Halley's creditable connection with the same. Then follows an account of methods of demonstrating the earth's rotation. Some explanation is given of Hagen's application of Atwood's machine and then Foucault's pendulum is shown in operation. After this are experiments with gyroscopes and an account of their application to the steering of ships. Then the law of gravity is applied to the motion of a comet and a mechanical method of drawing a parabola is given, and after this Halley's investigations into the comet which bears his name are treated at some length. Finally, some account of the behavior of comets generally is given.

The above gives some notion of the subjects taken up in the first lecture, and there is not space to go into the succeeding chapters in detail. They are full of interesting matters. Indeed the chief criticism I would make of the course is that the lectures are too full of ideas. It seems to me that the 'juvenile auditory' present at the lectures must have been very exceptional if its members were able to comprehend the wealth of matters presented to them. For real teaching I have found it better to discuss fewer subjects and deal with them in greater detail. A

superabundance of apparatus and experiment may be pleasing as pyrotechnics but it usually bewilders the audience unless they are informed on the subject already. Before one subject is understood properly another is rushed along and confusion results. Among previous Christmas lectures were Faraday's "Connection of the Physical Forces" and Ball's "Starland," which have always appeared to me as ideal juvenile courses. While full enough of experimental illustrations there is not an excessive number of subjects introduced.

In illustration of the extraordinary trouble taken to secure interesting demonstrations I might refer to the discussion of eclipses in the chapter on the sun. An elaborate presentation of an eclipse was enacted in the lecture room. First the astronomer chose a good site for the observations. Then the aid of His Majesty's forces was called in to erect the model piers, cœlostat and telescopic camera, while the whole performance of counting the seconds, exposing model photographic plates, and other parts of the performance were duly carried through. During this time, over the image of the sun on the screen the moon moved forward, eclipsed it and then slowly drew away. After all this there were moving pictures showing the hens going to roost as totality came on and running out again when it was over. Perhaps I might also refer to the exhibition of effects produced by liquid air at the close of the lecture on visits to the moon and planets. This surely had little connection with the subject under discussion, though the photograph reproduced in the book, showing the children (and the lecturer) enjoying the performance, would indicate that it was quite successful.

A few mistakes were detected. On page 42 are shown Barnard's two photographs of a comet and his composite of the two. The second picture is said to have been taken "an hour or two" after the first. I think it was an entire day. Figure 31, "The great nebula in Andromeda" is said to have been taken with the 40-inch Yerkes telescope. I believe it was secured with the 2-foot reflector. The field is too large for the great refractor. On page 152 and again on page 230 it is stated

that Bode organized the "celestial police" to hunt a missing planet. This is at variance with Grant's "History of Physical Astronomy" (p. 238) or Clerke's "History" (p. 72). On page 169 (top line) the velocity of light is misprinted as 188,000 miles a second. On page 267 there is a reference to "Betelgeuse, the brightest star in Orion." These slips can be corrected in a second edition which I am sure will soon be demanded.

C. A. CHANT.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

June, 1916

Temperature.— The mean temperature was below average from the Rocky Mountains eastward into Western Quebec, and was average or above over British Columbia and Eastern Quebec, and in most parts of the Maritime Provinces. The largest negative departures occurred in Manitoba and the Peninsula of Ontario, and the largest positive in Prince Edward Island and Yukon Territory.

Precipitation.— The rainfall was in excess of the average over the greater part of Canada, exclusive of British Columbia, Western Alberta, and a small section of Central Ontario, but it was only in the Peninsula of Ontario, and the Upper St. Lawrence Valley that the excess was very pronounced.

July, 1916

Temperature.— The mean temperature was above the average in all parts of Canada, exclusive of British Columbia and Northwestern Alberta and Eastern Nova Scotia. The strongest contrast lay between Western Ontario, where the positive departure ranged between 5° and 8°, and the interior of British Columbia, where the negative departure was equally large. The large

positive departure in Ontario diminished gradually eastward, until in Southern New Brunswick and Eastern Nova Scotia the monthly mean was either just normal or slightly below.

Precipitation.—Along the upper Pacific Coast, in the Yukon, Western Alberta, and from the Georgian Bay to the Gulf, the rainfall was, in amount, considerably less than the July average. In the Peninsula of Ontario and in the lower Ottawa Valley, the deficiency reached the proportions of a drought, relieved in scattered localities by thunderstorms. In many districts of Ontario the total fall for the month amounted to less than half of an inch. In Southern New Brunswick, Prince Edward Island, the District of Kenora, Western Manitoba, Southwestern Saskatchewan, and the greater part of the Fraser Valley the normal rainfall was exceeded. Barkerville, Swift Current, and Kenora reported unusally large amounts, at the latter place no less than twelve days with thunderstorms having been recorded.

Temperature for June and July, 1916

Station	June		July	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	88	32	82	32
British Columbia				
Atlin	84	28	72	32
Agassiz	88	42	86	42
Barkerville	75	24		
Kamloops	95	38	90	45
New Westminster	88	40	85	42
Prince Rupert	72	37	72	45
Vancouver	83	44	79	45
Victoria	81	44	80	45
Western Provinces				
Battleford	78	32	89	47
Calgary	82	34	87	40
Edmonton	77	29	80	38
Medicine Hat	87	38	94	46
Minnedosa	78	32	86	43
Moose Jaw	82	35	91	45
Oakbank	77	33	92	44
Portage la Prairie	79	34	95	49
Prince Albert	76	30	86	46
Qu'Appelle	78	34	86	44
Regina	79	35	89	42
Saskatoon	78	30	90	47
Souris	77	34	89	42
Swift Current	78	28	90	40
Winnipeg	80	34	96	48
Ontario				
Agincourt	80	38	99	52
Aurora	78	33	95	47
Bancroft	81	36	98	40
Barrie	77	36	101	51
Beatrice	76	33	92	45
Berlin	78	39	99	48
Bloomfield	77	43	90	53
Brantford				
Chapleau	78	31	95	39
Chatham			102	55
Clinton	78	38	95	50
Collingwood	80	34	97	44
Cottam	85	42	98	54
Georgetown	77	38	95	53
Goderich				
Gravenhurst				
Grimsby	84	43	99	56
Guelph	77	38	99	63
Haliburton	85	33	100	40
Huntsville	78	36	97	45
Kenora	83	35	92	52
Kinmount	81	35	95	43
Kingston	74	42	88	54
London	81	39	100	47
Lucknow	78	34	96	46
Markdale	79	34	98	45
North Gower	80	40	97	47
Oshawa	73	40	94	51
Ottawa	76	44	97	53
Paris	80	35	100	50
Parry Sound	80	34	98	50
Peterboro'	80	38	96	51
Port Arthur	76	36	98	48
Port Burwell				
Port Dover	76	40	93	52
Port Stanley	75	35	91	52
Queensborough	79	35	96	50
Ronville	77	37	97	43
Southampton	81	36	90	51
Sundridge				
Stonecliffe	86	34	96	42
Stony Creek	81	40	98	47
Toronto	78	40	100	54
Uxbridge	79	36	95	50
Wallaceburg	82	42	97	53
Welland	84	40	93	50
White River	79	28	95	34
Quebec				
Brome	80	35	93	42
Father Point	80	40	86	40
Montreal	80	50	92	54
Quebec	83	44	92	50
Sherbrooke	80	42	89	47
Maritime Provinces				
Charlottetown	74	38	84	50
Chatham	82	40	96	42
Dalhousie	76	40	88	45
Fredericton	81	39	93	43
Halifax	80	40	88	44
Moncton	80	32	91	41
St. John	74	40	78	46
Sussex	76	37	88	43
Sydney	78	32	88	38
Yarmouth	72	42	76	44

MAGNETIC OBSERVATIONS

May and June, 1916

During the months of May and June the magnetic records, which were obtained at Agincourt, show more or less disturbed conditions in the magnetic forces throughout, but there were no very noteworthy disturbances. The larger storms occurred on May 30 and 31 and June 29 and 30. Very few auroræ were reported from the Dominion Meteorological Stations during these months.

May, 1916		D. West	H	Z	I
	Mean of Month	° ′ 6 32·9	0·16001	0·58537	° ′ 74 42·7
	Maximum	7 03·6	0·16107	0·58670	
	Date of Maximum	31	30	21	
	Minimum	5 52·5	0·15811	0·58356	
	Date of Minimum	21	31	31	
	Monthly Range	1 11·1	0·00296	0·00314	
Mean Daily Amplitude	From hourly readings	0 12·7	0·00052	0·00025	
	From means of extremes	0 24·8	0·00108	0·00064	

June, 1916		D. West	H	Z	I
	Mean of Month	° ′ 6 32·2	0·16001	0·58532	° ′ 74 42·6
	Maximum	6 47·0	0·16158	0·58622	
	Date	30	29	22	
	Minimum	5 53·1	0·16004	0·58435	
	Date	30	8	30	
	Monthly Range	0 53·9	0·00154	0·00187	
Mean Daily Amplitude	From hourly readings	0 13·8	0·00051	0·00018	
	From means of extremes	0 21·4	0·00089	0·00042	

H and Z are expressed in C.G.S. units.

All results are reduced to International Magnetic Standard.

W. E. W. J.

Earthquake Records by the Milne Seismograph

TORONTO

Sir Frederic Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. A.C. = Air Currents.
Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1916	P. T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
		h m	h m	h m	h m	h m	mm.	
1600	June 2			0 11·7		A.C.	0·05	
1601	" 2			13 50·4?	14 12·3	A.C.	0·4	
				14 10·0				
1602	" 3			6 0·0?			0·05	A.C.
1603	" 6			13 53·0		14 2·5	0·05	Mixed up with
1604	" 7	A.C.		13 47·2	13 55·4	A.C.	0·2	A.C. going on.
	" 9	A.C. going on at time Ottawa records quake.						
	" 11	A.C. going on at time Victoria records quake.						1h 16m·6 G.T.
1605	" 15			12 49·4	12 56·7	A.C.	0·3	A.C. going on.
1606	" 19	1 25·0?	1 32·7	1 38·4	1 44·0	A.C.	0·5	A.C. going on
1607	" 20			7 28·9		7 52·4	0·05	16,105 km
1608	" 21			21 51·9	21 52·5	A.C.	1·7	Abrupt moveme't at beg.nn.ng of L.W. Tapered off and came abruptly to rest for a short time at 21h 57m 0
1609	" 24			7 15·8?		7 47·6	0·2	
				7 20·6				
1610	" 25			18 30·5?	18 57·9	A.C.	1·2	L. W. came in abruptly and grad. tapered off.
				18 37·1				
1611	" 30	3 7·2	3 14·7	3 18·1	3 31·7	6 18·5	1·2	5883 km. Repeat 4h 52m·2.
	July 5	Nothing to correspond to Victoria.						Sheet 1st to 8th a mass of A.C.
1612	" 8			9 1·4		A.C.	0·1	Sheet 8th to 15th a mass of A.C.
	" 15	A.C. going on when Victoria records a small earthquake.						
1613	" 22			6 16 5			0·05	Very doubtful as to being seismic.
	" 23	A.C. going on when Victoria records small quake.						Victoria records a minute quake at 6h 15m·5.
1614	" 28	17 50·9	17 53·6	17 56·4	17 58·3	Lost	1·1	

Period of boom 18 seconds. Pillar inclinations 1 mm. = 0″·50.

VICTORIA, B. C.

F. N. DENISON, SUPERINTENDENT.

No.	Date 1916	P.T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
		h m	h m	h m	h m	h m	mm.	
1602	June 2			0 11·2	0 14·1		0·1	
1603	" 2	14 11·4	14 16·2	14 21·7	14 26·1	14 41·0	0·2	3,070 km.
1604	" 3				6 01·9		0·1	
1605	" 6			13 53·2	13 53·7	14 00·1	0·2	
1606	" 11			0 51·4	0 53·8		0·2	
1607	" 11			1 16·7?	1 20·1		0·2	
1608	" 15	12 26·6	12 30·6	12 39·5	12 43·0	13 16·7	0·5	2,410 km.
1609	" 19			1 38·6?	1 44·6	1 59·9	0·5	
1610	" 21	21?		21?	?	22 56·5	0·5	Paper slipped.
1611	" 24			6 59·0	7 06·9	7 16·4	0·2	
1612	" 25	18 32·7	18 34·2	18 35·2	18 37·7	18 44·1	0·9	
1613	" 30	3 10·6	3 19·1	3 30·1?) 3 36·6)	3 37·6	5 10·1	5·0	8200 km.
1614	July 5	4 41·3?		4 43·8	4 44·7	4 50·7	0·2	
1615	" 8	9 55·5	9 57·2	10 00·2	10 01·7	10 20·0	0·2	2200 km.
1616	" 15	00 05·1?			00 07·6	00 13·00	0·1	
1617	" 22			6 15·5	6 17·5		0·1	
1618	" 23	?	?	?	11 14·0	?	0·1	
1619	" 28	18 10·2?	18 12·6	18 15·6	18 24·0	18 37·4?	0·2	1420 km.

Boom period 18 seconds. Pillar inclination 1 mm. = 0″·54

VERTICAL COMPONENT

Date 1916	P.T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
	h m s	h m s	h m s	h m s	h m s	μ	
June 30	3 10 6	3 19 7	3 36 7?	3 39 3		* 15	7,730 km.

* True earth movement.

J. Y.

ASTRONOMICAL NOTES

THE British Association for the Advancement of Science meets this year at Newcastle-upon-Tyne, from September 5th to the 9th, under the Presidency of Sir Arthur Evans. The General Secretaries for this year are Professor W. A. Herdman and Professor H. H. Turner, of Oxford.

Professor A. N. Whitehead is the President of the Mathematical and Physical Science Section; with Professor A. S. Eddington, of the Observatory, Cambridge, as Recording Secretary of the Mathematical and Physical Science Section.

Among the papers announced for this Section is one on "Gravitation" dealing with the relativity theories of Einstein and others, including their applications to astronomy. Papers of a general character will be read by Professor H. H. Turner, on the "Measurement of Time," by Sir E. Rutherford, on the "X-Ray Spectra of the Elements," and by Major P. A. MacMahon, on the "Partition of Numbers."

At the Annual Conference of the Delegates of Corresponding Societies, the following subjects, among others, will be discussed:—

1, "The Encouragement of Public Interest in Science by Means of Public Lectures."

2. "The Desirability of Forming Federations of Societies with Cognate Aims."

CONNECTING WINNECKE'S COMET WITH RECENT METEOR SHOWERS.—Harvard College Observatory *Bulletin* 614, August 3, 1916.—A letter received at this Observatory from Dr. Charles P. Olivier, of the Leander McCormick Observatory, contains the following statement:—

Unusual meteoric activity was reported for late May and early June by two members of the American Meteor Society, John

Koep and Philip Trudelle, of Chippewa Falls, Wis. Excellent radiants were obtained and parabolic orbits computed.

In *Nature* of July 10, 1916, an unusual shower was described which was observed in England by an observer at Birmingham on June 28·5. The comparison of all elements proves a probable connection between these meteor streams and Winnecke's Comet of 1909.

THE FUNCTION OF VAN VLECK OBSERVATORY.—There is evidently much doubt in the minds of some people as to just what an observatory is, and what it is for.

A teamster came up here some time ago with a load of window frames for the dormitory. When told that he had come to the wrong place, that this was the observatory not the dormitory, he paused a moment and then asked, "Well, what's the difference anyway?"

The observatory does not, as one of the papers stated last Sunday, combine all of the best features of the best observatories in Europe and America, but it does contain as many desirable features as our fund would allow.

The function of the Van Vleck Observatory of Wesleyan University, it seems to me, is twofold: instruction and research. In some universities there is a sharp line of demarcation between these two, and such a division may be necessary in the case of very large classes, but, to my mind, research is one form of instruction and instruction without research is apt to become dry. The two should go hand in hand, or at least, if possible, should be carried on under the same roof.

Someone has likened a course in astronomy to a trip abroad. The pleasure of travel and its broadening effect are, of course, recognized, and there is a similar widening of the vision from a personally conducted tour through the heavens with a telescope. From this point of view alone courses in astronomy would be justified, but there are other characteristics equally worth considering.

The courses now offered here at Wesleyan are of four quite different types. First there is a general descriptive course, chiefly

informational in character. A standard elementary textbook is used, and just enough laboratory work or rather observatory work is introduced to make the text perfectly clear. Second, a course in the history of astronomy. This might be classed as purely cultural. There is no adequate text on this subject, so of course is conducted by lectures illustrated with the telescope and by photographs and lantern slides.

We begin with the birth of astronomy among the shepherds on the Chaldean hills some 3000 years B.C., trace its development in Greece, noting especially the part it played in the philosophy of Pythagoras, Plato, and Aristotle, then follow its history in Alexandria, Babylon and Spain. Passing over the dark ages, we dwell a little longer upon the great revival in Europe, in which five great men stand out so prominently: Copernicus the Pole, Tycho Brahe the Dane, Kepler the German, Galileo the Italian, and Sir Isaac Newton the Englishman. At the hands of these five men the science of astronomy was completely revolutionized and started upon a new line of development, which has continued, ever becoming more extensive and intensive, culminating in the wonderful discoveries being made with the various forms of spectroscopes in recent times. Only the general characteristics and most prominent features of this development are discussed. The aim is to give the student a general idea of what is included in the science of astronomy, how the science has developed, and its relation to other branches of learning.

The third course is one in practical astronomy. The students from the very beginning use instruments, make observations, and reduce them. They deal with such problems as the determination of accurate time as used for railroad and other commercial purposes, and the determination of latitude, longitude, and azimuth, as used in the higher surveying on land, and in navigation at sea.

The remaining courses may be included in one class. They are all laboratory courses and deal with the more difficult problems of theoretical and practical astronomy. They may be grouped together because of one common characteristic. These classes will always be small and the students will, to some extent,

take part in the routine research work of the observatory, thus getting some insight into the methods of modern astronomical investigation.—FREDERICK SLOCUM, *Popular Astronomy*, August, 1916.

LOWEST EFFECTIVE POWER OF A TELESCOPE.—The following taken from *Journal B. A. A.*, Vol. XXVI., p. 302, appears in the issue of *Nature* of August 10th.—It has usually been considered that the lowest power which can be employed on a telescope, while retaining full illumination, is one of five to each inch of aperture, this estimate being based on the assumption that the average diameter of the pupil of the eye is one-fifth of an inch. Mr. W. H. Steavenson has investigated the diameter of the pupil by flashlight photography, and has found that while one-fifth of an inch may be a fair estimate of the aperture in daylight, one-third of an inch is much nearer the aperture at night. An interesting application of this result has been made by Naval Instructor M. A. Ainslie, R.N., in connection with the 72-in. mirror of the Rosse reflector, now included in the collection at the Science Museum. The "original" eyepiece of the great telescope has been found to have an equivalent focal length of 7·7 in., giving a magnifying power of 84 and an emergent pencil of 0·855 in. diameter. It follows that the effective aperture of the speculum, when this eyepiece was used, would be only 25 in., or approximately equal in light-gathering power to a refractor of 20-in. aperture. A power not less than 216 would be necessary to give the full benefit of the large mirror. Although the eyepiece in question was not the only one employed, it may be important to take account of the fact that some of the observations at Parsonstown were not made with the full aperture of the telescope.

VARIABILITY OF SOLAR TEMPERATURE AND RADIATION.—It is well known that so slight an envelope as our terrestrial atmosphere scatters something like 10 per cent. out of the direct solar beam. If we compare the gigantic sun with the pigmy earth it is apparent that even a "thin" atmosphere on the sun must scatter much more. Under solar conditions, contrasted with terrestrial ones, scattering takes place on rays arising from every direction instead of from one direction alone. Accordingly the beam which seems to come from the centre of the sun's disc really

comes largely by scattering from all sides. On this account we regard Biscoe's "co-efficients of transmission of the solar atmosphere" as quite without foundation.

Our own investigations have convinced us that some of the days we have included in Mount Wilson results of each and every year are affected by unfavorable atmospheric conditions. Such days are likely closely to precede and follow storms, periods of cloudiness, or periods of great humidity. We have not thought best hitherto utterly to exclude such days, partly because it is difficult to frame a suitable criterion for exclusion, and partly because we alone are making solar-constant observations, and an unsatisfactory value may be better than none.

These admissions made, we stand by the variability of the sun; by the proof of it in the work of 1912; by the close accuracy of our mean value of the solar constant of radiation; and by the soundness of our methods of solar-constant determination.

The variability of the sun is now confirmed by (*a*) Mount Wilson observations of the solar constant, (*b*) comparison of Mount Wilson and Bassour observations, (*c*) comparison of Mount Wilson and Arequipa observations, (*d*) comparison of Mount Wilson and magnetic observations, (*e*) comparison of Mount Wilson solar-constant work with Mount Wilson solar-constrast work. The cumulative effect of this evidence is overwhelming.

Hence we may conclude that while some of the very best Mount Wilson solar-constant results indicate large solar variation, they show no dependence on the atmospheric transparency.— ABBOT, FOWLE and ALDRICH, *Astrophysical Journal*, July, 1916.

VARIATION OF THE SOLAR ROTATION.— The investigation of the rotation period of the sun by spectroscopic methods has received an exceptionally large amount of attention from astrophysicists during the past ten years. The remarkable character of the law of the sun's rotation and the possibilities of variation in rotation period and in the behavior of different elements have combined to add to the attraction which a radial velocity investigation of high precision naturally possesses for astronomers.

In this volume of the "Annals of the Solar Physics Observatory of Cambridge" Vol. III., Part 1., are contained the results of an investigation of the solar rotation by Dr. Hubrecht in June,

1911. The most interesting feature of Dr. Hubrecht's observations is the fact that these comparisons were made between points distant from one another by 90° of latitude instead of 180°, as in investigation by previous observers. This has made it possible to discuss the question of the symmetry of the rotation law in the two solar hemispheres.

From a discussion of his results Dr. Hubrecht arrives at the important conclusion that there is a variation of velocity with wave-length amounting to about 3 per cent. at a maximum in the interval between λ4300 and λ4400. This difference, after an extended discussion of other possible causes, the author concludes to be due to ray curving in the solar atmosphere, a result which will probably be accepted with some question by astronomers. Naturally the chief objection to this explanation is that if carried to its logical conclusion the difference between the values obtained in the violet and the yellow and red portions of the spectrum should be very large, much larger than there is as yet any reason to suppose.

The result of a comparison of individual lines and elements indicates no certain differences of velocity for different elements, a conclusion in agreement with that of other observers except those at Mount Wilson and Marseilles.

The lack of symmetry found by Dr. Hubrecht between the Northern and Southern hemispheres as regards rotational values is a result of great interest, and provides ample justification for the method of observation adopted by him. The existence of local drifts during the comparatively short interval of time covered by the observations is a most probable explanation of the differences obtained. This may, perhaps, account as well for, at least, a part of the discrepancy between his result of 13°·2 for the angular velocity at the equator and that of Plaskett of 14°·4 for a slightly later epoch. In view of the probability of a variation in the sun's period of rotation, as shown by recent observations, such a comparison should be limited to results of closely the same date.

Although some of the results obtained from this investigation of Dr. Hubrecht must await confirmation from future observations, the questions raised will add materially to the interest already attaching to the study of this important problem.—W. S. Adams, in *Astrophysical Journal*, July, 1916. J. R. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

RAINFALL AND CANNONADING

During the present war the question of the production of rainfall by gun-fire has continually arisen. In the *Scientific American* for October 24, 1914, is an excellent editorial article on the subject; in the *Scientific Monthly* for February, 1916, is a discussion by Professor A. G. McAdie; while in the *Popular Science Monthly* for January, 1911, Professor Cleveland Abbe showed by laboratory experiments that the firing of cannon or dynamite could not possibly produce rain.

A comparison of the amounts of energy involved in an ordinary rain storm and in the discharge of artillery, enormous though the latter may be, shows that the two phenomena are really in different classes of magnitudes. Of course the energy of the discharge, while not sufficient directly to produce the rain, might in some way set free atmospheric forces ready to act, just as pulling the trigger fires the gun. But even considered in this way, the cannonading would not be sufficient.

In a recent issue of *Science* Professor Charles F. Brooks, in a brief discussion of the weather and the war, refers to this matter. The winter of 1914–1915 in the British Isles was excessively wet and caused much comment. At a meeting of the Royal Meteorological Society, Charles Harding presented a summary of the weather conditions for eight stations in Great Britain and eight on the continent for the period August, 1914, to April, 1915; and in connection with the discussion regarding

the cause of the great rainfall in England, Dr. Hugh R. Mill, Director of the British Rainfall Organization, made the following statement :—

> The vastness of the work done by the quiet processes of nature requires only to be realized in order to show the incalculable improbability of gunfire in France producing a wet winter in England. Take the case of the three and a half inches of rain which fell in excess of the average in December over 58,000 square miles of England and Wales. This quantity is 203,000 square mile inches or 13,126,920,000 tons. At winter temperatures, saturated water vapor would form about 1 per cent. of the mass of the atmosphere containing it, hence the minimum quantity of air which must have been carried over England and Wales in December, 1914, must have exceeded 1,300,000,000,000 tons. The amount of force required even to deviate the direction of moving masses of this magnitude is surely far beyond that which can be exerted even by nations at war.

THE HUNDREDTH ANNIVERSARY OF THE U.S. COAST AND GEODETIC SURVEY

The celebration last year of the hundred years of peace between the United States and Great Britain and the more recent celebration of the centenary of the U.S. Coast and Geodetic Survey are incidents which remind us that our institutions are attaining the flower of age. It is also interesting to think that these two matters are related in another way, since the Survey has had much to do with the delimitation of our long international boundary on which there is no fort or other suggestion of war.

In the hundred years of its existence the Survey has passed through many vicissitudes, and though it has had ten superintendents, for the first half of its life it had but two. Hassler, the founder, served for 26 years ; and Bache, his successor, for 25 years. During this time the character of the organization was firmly established. It has never suffered by comparison with the geodetic surveys of the old lands. Its operations have always been executed with a degree of precision which excites admiration, and though there has been criticism on account of the apparent slowness of some of its work, no fault has ever been

found for not keeping that work up to the highest standard. In discussing the 'efficiency' of such an organization the first essential to consider is the quality rather than the quantity of the output. Work which has to be revised at a later date is usually more expensive in the end. Thus far the work of our own Geodetic Survey has been on a very modest scale, but whatever may be undertaken, it is desirable that it be done with such accuracy that future developments may not require it to be done over again.

C. A. C.